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RESEARCH MEMORANDUM

COMBUSTION EFFICIENCY OF HOMOGENEOUS FUEL-AIR MIXTURES IN A 5-INCH RAM-JET-TYPE COMBUSTOR

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NATIONAL ADVISORY COMMITTEE
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COMBUSTION EFFICIENCY OF HOMOGENEOUS FUEL-AIR MIXTURES IN A 5-INCH RAM-JET-TYPE COMBUSTOR

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SUMMARY

Combustion-efficiency data have been obtained for a 5-inch-diameter combustor employing a straight V-gutter flame holder and a simple cone flame holder. The data obtained cover a range of inlet static pressures, temperatures, and velocities for four fuels.

The data have been shown to correlate with the inlet flow variables of static pressure P, temperature T, and velocity V by the empirical parameter $P^{0.3}T/V^{0.8}$ and also with fuel variations by means of a fundamental flame-speed relation.

It has also been shown that the data are in agreement with a mechanism based on the concept that the rate of flame propagation through the unburned mixture is a function of the fundamental flame speed.

INTRODUCTION

The combustion process in a ram-jet engine or other engines requiring a similar high-speed combustion process may be considered to be a stepwise process where (1) the liquid fuel is sprayed into the high-velocity stream, (2) the spray disintegrates into a myriad of drops, (3) the drops vaporize, (4) the fuel mixes with the air stream to form a combustible mixture, (5) the mixture is ignited, and (6) the flame spreads through the unburned mixture. An attempt to evaluate the importance of any one of these steps in controlling the rate of the over-all process is obviously difficult in a system in which all the steps vary simultaneously.

It is possible to treat, analytically and experimentally, the preparation of the fuel-air mixture (steps 1 to 4) separately from the combustion steps, and to evaluate the effects of various conditions of inlet static pressure, temperature, and velocity on the fuel-air mixture parameters.

Also, it is possible to investigate the combustion process separately from the fuel preparation by the use of homogeneous fuel-air mixtures.

Such an experimentally idealized system does not necessarily represent a practical ram-jet-type combustor, but will contribute to a better understanding of high-speed combustion processes for such an application. In a practical application, carburetion features can seldom be so simplified as they are herein for study purposes.

Several investigations have been carried out on the effect of mixture parameters on the stability of flame-holding elements in homogeneous fuel-air mixtures (references 1 to 3). The object of the present investigation carried out at the NACA Lewis laboratory was to determine the effect of inlet static pressure, temperature, velocity, and fuel-air ratio on the combustion efficiency of a ram-jet-type combustor with homogeneous fuel-air mixtures.

A second objective was to investigate the effect of flame speed on the combustion efficiency by the use of different fuels. Thus, this report is concerned mainly with flame propagation as distinct from flame stability as reported for similar idealized combustion equipment in references 1 to 3.

No attempt was made to design a combustor which would be particularly efficient under any specified set of operating conditions, but rather two flame holders were selected which would operate stably over a wide range of conditions and which would be representative of flame holders in common use.

This report presents the results of combustion-efficiency measurements of two flame holders and four fuels over a range of inlet static pressures, temperatures, velocities, and fuel-air ratios. A correlation of the data is presented and a proposed mechanism for the propagation is discussed.

SYMBOLS

The following symbols are used in this report:

A	area, sq ft
a_f	flame area per unit volume of mixture, ft^{-1}
c	arbitrary constant
d	characteristic diameter, ft
K	constant
L	combustor length, ft

m mass air flow, lb/sec

P inlet static pressure, atm

Re Reynolds number, $dV\rho/\mu$

T inlet mixture temperature, $^{\circ}R$

T_b inlet temperature before fuel introduction, $^{\circ}R$

u_f fundamental flame speed of fuel-air mixture, ft/sec

V inlet mixture velocity, ft/sec

η combustion efficiency, percent

μ viscosity, lb-ft/sec

ρ density, lb/cu ft

φ' function

Subscripts:

c combustor

f flame

f,g flame, gasoline

u unburned mixture

Superscripts:

a exponent

b exponent

APPARATUS AND PROCEDURE

A schematic layout of the combustor and piping used in this investigation is shown in figure 1. The combustor was a jacketed section of 5-inch standard pipe. The over-all length from the flame holder to the exit quench spray location was 36 inches. The flame holder used for most of the data was a $1\frac{1}{2}$-inch wide straight V-gutter of approximately 45°

included angle and blocked about 38 percent of the combustor cross-sectional area. Ignition was accomplished by introducing a hydrogen-oxygen pilot flame behind the flame holder at either end. The pilot was turned off after the burner was ignited. A cone flame holder was used in part of the investigation; it consisted of a 60° cone with two small gutters extending to the wall for support and blocked about 40 percent of the combustor cross-sectional area. A variable-area exhaust nozzle, manually controlled, was used to control the burner pressure.

The procedure used to obtain the test data was to set the mass air flow and air temperature at predetermined values. The air temperature had to be set at about 50° F above the desired inlet mixture temperature to allow for temperature drop due to vaporization of the fuel. Then, after the burner was ignited and the desired fuel flow established, the inlet static pressure was set by controlling the exhaust-nozzle area. Quench water was sprayed into the exhaust stream at the exit of the combustor to bring the gas temperature down to about 500° F. The combustion efficiency was calculated by an enthalpy balance. Spot checks by gas analysis of the exhaust stream gave combustion-efficiency measurements that agreed within 2 percent with the heat-balance calculations.

With this procedure, data were taken over the following range of combustor inlet conditions: static pressure, 1/2 to 2 atmospheres; mixture temperature, 100° to 300° F; and velocity, 170 to 300 feet per second.

RESULTS AND DISCUSSION

A summary of the data on the V-gutter is given in tables I and II. Plots of the combustion efficiency against the fuel-air ratio for several of the data conditions given in tables I and II are shown in figures 2 and 3. It is evident from these plots that over the range of conditions studied, for both gasoline and isopentane, the combustion efficiency was essentially independent of the fuel-air ratio. This effect was unexpected inasmuch as most data reported have a peak in the curve of combustion efficiency plotted against fuel-air ratio. The data of this report, however, are for homogeneous fuel-air mixtures, cover only a limited range of fuel-air ratios, and, further, do not have variations of inlet conditions with fuel-air ratio since a variable-area exit nozzle was used to maintain constant inlet conditions. Even so, it might be expected that the flame would propagate more rapidly through near-stoichiometric mixtures than it would through leaner or richer mixtures giving a higher combustion efficiency at near-stoichiometric mixtures. It is the case, however, that even though the inlet velocities may be the same for two fuel-air ratio conditions, the residence time for the fuel-air mixture in the combustion chamber will be less for the higher temperature-rise condition. The resulting residence-time propagation-rate product must be approximately the same for the range of fuel-air ratios encountered in this investigation.

Table III contains a summary of the data plotted in figures 2 and 3 at a fuel-air ratio of about stoichiometric. It was desired to fit these data to a common correlating equation if possible. It was found that the combustion efficiency could be expressed as a simple power function of the inlet parameters in the range of combustion efficiencies covered in this investigation. Figures 4, 5, and 6, respectively, show plots of combustion efficiency against static pressure, temperature, and velocity on log-log scale. If an average slope for the lines on each of the three figures is taken, then the combustion efficiency may be expressed by the relation

$$\eta_b = CP^{0.3} T^{1.0}/V^{0.8}$$

A plot of all the data in table III is shown in figure 7. In this figure, combustion efficiency is plotted against the empirically derived parameter above. It is evident from this plot that all the combustion-efficiency data on the 5-inch combustor with the V-gutter flame holder over the range of conditions covered can be expressed by the equation

$$\eta_b = 7.0 \frac{P^{0.3} T}{V^{0.8}}$$

where η_b is expressed in percent, P in atmospheres, T in degrees Rankine, and V in feet per second, within an average deviation of less than 3 percent in combustion efficiency. Although an extension of the equation would predict 100 percent combustion efficiency at or above some value of the correlating parameter, the exponents of the parameter do not apply at efficiencies much higher than those encountered in this experimental work. Hence an extrapolation of the parameter would not be justifiable at higher efficiencies. This point will be discussed later on in this section. From some data available in the literature on a similar system (homogeneous pentane-air mixtures in a 2-in. burner) (reference 4), the parameter was shown to correlate when extended at the lower efficiency range. These data (table IV) cover a static pressure range of 0.133 to 2.9 atmospheres, or greater than 20 to 1. These data are also shown in figure 7. The fact that the data fall on a straight line is significant; that this line is the same straight line as for the 5-inch combustor data is coincidental, since these data were obtained in a different combustor configuration.

To see whether this correlation parameter would apply to another type of flame holder, combustion-efficiency data were taken over a range of combustor-inlet conditions with the cone flame holder. These data are shown in table V and are plotted in figure 8. Although the combustion efficiency against fuel-air ratio curves are not flat as was the curve with the V-gutter flame holder, a comparison is made with the previously

derived parameter at the stoichiometric fuel-air condition. These data are shown in table VI and are plotted in figure 9. The agreement with the cone flame holder, although not as good as with the V-gutter flame holder, is reasonable.

The foregoing results are in accord with a suggested mechanism of the combustion process based on the fundamental flame speed of the mixture. An instantaneous cross-sectional view of the flame in the combustor is pictured in figure 10. It is supposed that as the flame propagates into the unburned mixture of fuel and air, turbulence existing in the combustor causes isolated volumes of mixture to form. The total flame area is increased by the high degree of turbulence, and the flame propagates through these isolated volumes at the fundamental flame speed of the mixture.

The combustion efficiency may be expressed as follows:

$$\eta = \frac{\rho_u A_f u_f}{\rho_u A_c V} \tag{1}$$

The numerator represents the mass of combustible consumed by the flame per unit time; the denominator represents the mass flowing through the combustor per unit time. Since $A_f = \int_0^V a_f \, dV = A_c \int_0^L a_f \, dL$, equation (1) can be written in differential form as

$$\int_0^\eta d\eta = \frac{\rho_u A_c u_f \int_0^L a_f \, dL}{\rho_u A_c V} \tag{2}$$

It can be assumed that the flame area per unit volume of mixture a_f is a function of both Reynolds number (which is an index of the turbulent-flow pattern) and u_f/V (which determines the change in flame area per unit volume as the mixture flows through the combustor); that is,

$$a_f = \varphi' \left(Re, \frac{u_f}{V} \right) \tag{3}$$

Then, equation (2) may be expressed as

$$\eta_b = \frac{A_c u_f}{A_c V} \int_0^{L_c} \varphi' \left(Re, \frac{u_f}{V} \right) dL \tag{4}$$

The assumption was made (as found in reference 5) that the dependence of flame area on the Reynolds number is

$$A_f = c\ Re^a \tag{5}$$

It should be noted that in reference 5 only diameter and velocity terms were varied in obtaining the Reynolds number dependence. Nevertheless, this Reynolds number dependence is assumed to hold for variations in density and viscosity, also in the development following.

The expression is further simplified by assuming that the function, $\varphi'(u_f/V)$ can be expressed in the form $(u_f/V)^b$. When this assumption is applied, equations (4) and (5) become

$$\eta_b = c\ Re^a \left(\frac{u_f}{V}\right)^b L_c = K\ Re^a \left(\frac{u_f}{V}\right)^b \tag{6}$$

The Reynolds number can be expressed in terms of the inlet parameters for this study by the following transformation:

$$Re = dV\rho/\mu$$

But ρ is proportional to PT^{-1}, and in the temperature range investigated, μ is proportional to $T^{0.7}$; therefore, the Reynolds number variation is proportional to $PV/T^{1.7}$. Flame velocity for isooctane (assumed representative as to temperature variation for the gasoline used in this investigation) has been found to be proportional to $T^{1.4}$ in the range of inlet temperatures under consideration (reference 6). The dependence of flame speed on pressure is subject to question. A survey of the literature indicates somewhat conflicting results, with u_f depending on pressure from small-positive, zero, to small-negative exponents. Since the dependence is uncertain, herein u_f is assumed independent of static pressure. Equation (6) can then be expressed

$$\eta_b = c \left(\frac{PV}{T^{1.7}}\right)^a \left(\frac{T^{1.4}}{V}\right)^b \tag{7}$$

Values of $a = 0.3$ and $b = 1.1$ reduce this expression to

$$\eta_b = c\ \frac{P^{0.3}\ T^{1.03}}{V^{0.8}} \tag{8}$$

This parameter is essentially identical to the empirically derived one. The exponent $a = 0.3$ is close to the value of 0.24 found in reference 5.

To further check on the possible validity of this propagation mechanism and to investigate the applicability of the flame-speed term, two additional fuels were investigated which had fundamental flame speeds higher than that for gasoline. These were benzene, with u_f of about 12 percent greater than gasoline, and propylene oxide, with u_f of about 60 percent greater than gasoline (reference 7).

These two fuels were run at two sets of conditions: P = 2/3 atmosphere, T = 200° F, V = 285 feet per second; and P = 2/3 atmosphere, T = 200° F, V = 185 feet per second. Propylene oxide was also run at an inlet static pressure of 1/3 atmosphere. The results are shown in tables VII and VIII and are plotted in figure 11. A comparison of these fuels with the gasoline curve of figure 7 at an equivalence ratio of 1.0 is shown in figure 12. On this figure, the P, T, and V parameter for the benzene and propylene oxide points have been multiplied by the ratios of the flame speeds raised to the 1.1 power as equation (7) showed to be required (see table IX). Figure 12 indicates that the performance of these three fuels is correlated by the common line, a fact which lends support to the assumed combustion mechanism.

As was mentioned previously, it was not anticipated that the straight-line correlation would hold much beyond the efficiency range of about 80 percent covered in this investigation. This limitation of the correlation is evident also in the higher efficiency point for the propylene oxide. A possible explanation for this limitation of the correlation is as follows: a schematic illustration of an instantaneous flame zone is shown in figure 10. When conditions are such that the flame is spreading outward toward the wall at such a rate that the outer flame envelope is approaching or touching the wall at the downstream end of the combustor, any change in conditions tending toward higher combustion efficiencies would not likely cause the same relative effect on the combustion efficiency as occurs in the lower efficiency range. As the flame approaches the wall, the cooling and quenching effect of the wall comes into play and the mechanism governing propagation and, therefore, any correlation of performance data, are, of course, appreciably modified. Proof of this is shown by some curves of combustion efficiency plotted against combustor length presented in reference 8. The general shapes of the curves are as shown in figure 13(a). The data for these curves were for a constant-area exhaust and, hence, any reduction in combustion efficiency as the length was varied caused inlet velocity to increase and inlet static pressure to decrease. However, if these data are normalized to constant inlet static pressure and velocity conditions by means of the parameter derived in the present study, the straight

line portion of the curve is still obtained although the slope is considerably smaller (fig. 13(a)). This same sort of behavior is anticipated whether the variable tending to change the combustion efficiency be combustor length, static pressure, temperature, velocity, or flame speed. In other words, the combustion efficiency against combustor length curve would be expected to change with changing conditions as shown in the curves in figures 13(b) to 13(e), with the actual combustor length L_c giving the change of combustion efficiency with conditions as would be read from this sequence of curves.

If the conditions are such that the combustion efficiency for the given combustor is about 80 percent, and, if then one of these conditions, for example, flame speed, is increased, the combustion efficiency would increase but no longer in the same proportion as in the lower efficiency range (fig. 13(e)).

This sort of behavior is probably the reason that the combustion efficiency against inlet parameter curve decreases rapidly in slope beyond about 80-percent efficiency.

CONCLUDING REMARKS

The results obtained in investigations with a 5-inch-diameter ram-jet-type combustor employing two flame holders (a straight V-gutter and a cone) and homogeneous fuel-air mixtures of four fuels (gasoline, isopentane, benzene, and propylene oxide) are summarized as follows:

1. The majority of data indicated that the combustion efficiency was relatively insensitive to fuel-air ratio over the range of fuel-air ratios investigated.

2. The data obtained with the V-gutter flame holder using gasoline and isopentane (which have approximately the same fundamental flame speed) were correlated by the equation

$$\eta_b = 7.0 \frac{P^{0.3} T}{V^{0.8}}$$

where P is combustor-inlet static pressure in atmospheres, T is combustor-inlet temperature in degrees Rankine, V is combustor-inlet velocity in feet per second, and η_b is combustion efficiency in percent.

3. The data on propylene oxide and benzene were also correlated with this same equation when it was multiplied by the ratio of the fundamental flame speeds of the fuels raised to the 1.1 power. For the fuels tested

$$\eta_b = 7.0 \frac{P^{0.3} T}{V^{0.8}} \left(\frac{u_f}{u_{f,g}} \right)^{1.1}$$

where $u_{f,g}$ is the fundamental flame speed of the reference fuel (gasoline).

4. A mechanism of flame propagation which yields the same parameter as that empirically derived is explained and has been shown to be consistent with the data as to both variations in inlet conditions of static pressure, temperature, and velocity, and to variations in fuels.

5. The application of these equations is indicated to be limited to efficiencies not exceeding about 80 percent; the reason for this limitation is surmised to be a modification of flame propagation mechanism as the propagating flame approaches the combustor walls.

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TABLE I - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH GASOLINE

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b (^oR)	Inlet temperature T (^oR)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a
0.50	1.24	0.0659	681	632	0.0325	274	36.6		
.50	1.24	.0654	681	633	.0324	274	37.7		
.50	1.24	.0604	681	634	.0323	275	38.3		
.50	1.24	.0650	682	635	.0323	275	37.2		
.50	1.24	.0605	682	636	.0322	276	38.6		
.50	1.24	.0568	682	637	.0322	275	39.8	0.0537	
.50	1.24	.0628	683	635	.0323	274	37.9		0.0683
.50	1.24	.0655	683	632	.0324	274	37.4		
.50	1.06	.0600	680	637	.0322	235	46.5		
.50	1.06	.0579	679	636	.0322	235	47.5		
.50	1.06	.0547	678	634	.0324	234	47.0		
.50	1.06	.0566	678	637	.0322	235	47.2		
.50	1.06	.0591	678	634	.0323	234	46.7		
.50	1.06	.0626	678	631	.0325	233	45.3		
.50	1.06	.0655	678	628	.0326	233	43.5		.0670
.50	1.06	.0577	678	634	.0323	235	47.2		
.50	1.19	.0549	641	604	.0340	251	38.1		
.50	1.15	.0593	645	604	.0335	245	39.4		
.50	1.15	.0613	645	602	.0343	241	40.7		
.50	1.19	.0633	644	600	.0342	248	38.0		
.50	1.20	.0658	642	597	.0346	249	36.3		.0688
.50	1.08	.0610	637	594	.0345	224	42.9		
.50	1.08	.0578	635	595	.0345	225	43.9	.0507	
.75	1.68	.0562	656	615	.0484	249	50.2		
.75	1.67	.0665	656	617	.0491	244	47.8		
.75	1.62	.0737	659	605	.0493	235	52.8		.0772
.75	1.64	.0542	658	618	.0482	244	53.0	.0517	
.75	1.25	.0556	680	635	.0475	189	66.0		
.75	1.83	.0607	680	636	.0471	278	43.7		
.75	1.81	.0691	684	631	.0474	274	47.1		
.75	1.81	.0767	686	628	.0479	271	49.4		.0790
.75	1.82	.0534	686	641	.0469	278	44.8		
.75	1.83	.0493	686	645	.0466	281	46.5	.0487	
.75	1.66	.0502	756	710	.0419	284	53.1		
.75	1.68	.0579	756	703	.0424	284	52.5		.0753
.75	1.69	.0657	756	697	.0427	284	50.2		
.75	1.66	.0753	760	693	.0432	275	52.9	.0444	
.75	1.59	.0480	774	727	.0411	277	55.0		
.75	1.45	.0479	766	723	.0414	251	59.4	.0478	
.75	1.45	.0575	760	712	.0420	247	57.9		
.75	1.47	.0661	756	695	.0430	245	56.9		.0776
.75	1.47	.0756	752	685	.0437	241	60.5		
.75	1.12	.0620	747	692	.0430	187	69.9	.0620	.0745
.75	1.11	.0751	736	675	.0443	180	69.4		
.75	1.68	.0496	776	729	.0408	295	52.3		
.75	1.68	.0537	776	726	.0410	294	53.7		
.75	1.68	.0579	777	723	.0412	292	55.0		
.75	1.68	.0620	776	719	.0414	291	53.5		
.75	1.67	.0665	776	716	.0419	286	55.8		
.75	1.68	.0703	777	713	.0418	288	54.3		
.75	1.68	.0744	778	709	.0420	287	53.0		.0777
.75	1.67	.0765	779	710	.0419	286	52.2		
.75	1.68	.0711	778	712	.0418	288	51.6		
.75	1.68	.0678	779	715	.0416	289	51.0		
.75	1.68	.0637	780	719	.0414	291	53.0		
.75	1.68	.0595	779	722	.0412	292	53.9		
.75	1.68	.0554	779	725	.0418	294	53.1		
.75	1.68	.0513	779	729	.0408	295	55.0	.0472	
.75	1.68	.0529	780	729	.0408	295	52.6		
.75	1.68	.0496	780	732	.0407	296	53.2		
.75	1.88	.0576	679	633	.0470	287	44.0		
.75	1.88	.0665	680	629	.0473	285	42.0		
.75	1.89	.0735	682	625	.0476	284	46.9		
.75	1.89	.0772	684	625	.0476	284	47.8		.0793
.75	1.88	.0754	686	627	.0475	284	48.4		

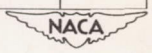

TABLE I - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH GASOLINE - Continued

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b (°R)	Inlet temperature T (°R)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a
0.75	1.88	0.0702	687	630	0.0473	285	45.9		
.75	1.89	.0647	687	635	.0469	289	42.3		
.75	1.89	.0610	688	639	.0466	291	43.5		
.75	1.89	.0566	688	641	.0465	291	44.8		
.75	1.89	.0536	688	644	.0462	293	44.4		
.75	1.90	.0512	688	645	.0461	295	43.9		
.75	1.89	.0478	688	649	.0459	295	44.1		
.75	1.26	.0650	682	631	.0472	191	63.4		
.75	1.26	.0716	682	626	.0475	190	65.4		0.0752
.75	1.25	.0611	681	635	.0469	191	64.9		
.75	1.25	.0678	682	630	.0473	189	62.1		
.75	1.25	.0722	682	628	.0474	189	63.7		.0734
.75	1.25	.0603	682	634	.0469	189	61.6		
.75	1.57	.0584	700	655	.0454	248	52.8		
.75	1.57	.0566	700	657	.0453	248	54.5		
.75	1.57	.0589	702	657	.0453	248	53.4		
.75	1.57	.0587	703	658	.0452	249	53.1		
.75	1.57	.0584	703	658	.0453	248	53.7		
.75	1.57	.0663	703	653	.0456	247	50.6		
.75	1.57	.0663	704	653	.0456	247	50.4		
.75	1.57	.0734	704	646	.0461	244	53.5		
.75	1.57	.0734	704	647	.0460	244	52.0		
.75	1.57	.0725	704	647	.0466	241	54.1		
.75	1.57	.0575	707	662	.0450	250	52.9		
.75	1.57	.0570	707	666	.0437	257	51.9		
.75	1.57	.0566	707	662	.0447	252	53.9		
.75	1.57	.0566	707	667	.0438	257	53.5		
1.00	1.60	.0616	663	615	.0645	178	73.6		
1.00	1.62	.0772	661	598	.0663	175	70.9	0.0540	.0800
1.00	1.95	.0570	657	629	.0631	221	65.1		
1.00	1.96	.0666	667	618	.0642	219	63.4		
1.00	1.96	.0808	668	605	.0656	214	64.4	.0524	.0843
1.00	2.58	.0484	659	623	.0643	288	47.1		
1.00	2.58	.0592	658	614	.0647	286	47.6		
1.00	2.56	.0684	660	607	.0653	281	46.3	.0456	
1.00	2.13	.0522	758	712	.0558	274	56.7		
1.00	2.14	.0649	760	704	.0565	271	54.9		
1.00	2.14	.0779	760	694	.0572	268	61.3		.0843
1.00	2.14	.0461	760	719	.0553	277	57.0	.0442	
1.00	1.73	.0642	761	709	.0560	221	66.3		
1.00	1.73	.0803	760	702	.0564	220	70.5		.0850
1.00	1.75	.0516	755	707	.0561	224	68.0	.0500	
1.00	1.44	.0598	757	711	.0558	188	76.4		
1.00	1.45	.0642	755	699	.0567	183	74.8	.0490	.0690
1.00	1.40	.0546	760	710	.0559	180	77.9		
1.00	1.63	.0682	652	595	.0668	175	71.5		
1.00	1.64	.0737	652	589	.0674	174	72.0		
1.00	1.62	.0617	661	617	.0644	180	70.3		
1.00	1.62	.0557	663	616	.0643	181	72.5		
1.00	1.61	.0526	665	620	.0641	180	71.1	.0510	.0785
1.00	1.98	.0575	665	625	.0635	224	61.1		
1.00	1.98	.0575	665	625	.0635	224	61.1		
1.00	2.02	.0509	665	624	.0635	228	59.2	.0495	
1.00	1.98	.0631	664	615	.0646	220	61.6		
1.00	1.98	.0687	664	611	.0649	218	63.5		
1.00	1.99	.0733	664	607	.0653	219	61.6		
1.00	1.98	.0788	664	602	.0659	215	64.8		
1.00	1.98	.0814	664	599	.0663	214	62.6		.0828
1.00	2.60	.0491	657	621	.0639	292	42.5		
1.00	2.59	.0536	657	617	.0643	289	44.7		
1.00	2.58	.0581	659	614	.0647	286	45.6		
1.00	1.57	.0540	668	625	.0635	177	74.8		
1.00	1.57	.0513	688	649	.0612	184	71.4	.0487	
1.00	1.69	.0510	664	661	.0601	201	67.8		
1.00	1.61	.0531	690	646	.0599	192	73.9		

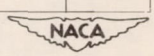

TABLE I - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH GASOLINE - Continued

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b (^oR)	Inlet temperature T (^oR)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a
1.00	1.68	0.0564	686	643	0.0617	194	69.8		
1.00	1.62	.0617	688	637	.0623	186	72.6	0.0480	0.0772
1.00	1.63	.0503	688	648	.0613	190	70.4		
1.00	1.63	.0684	690	637	.0624	187	70.4		
1.00	1.58	.0703	704	645	.0615	184	72.6		
1.00	1.89	.0551	670	628	.0632	214	64.2		
1.00	1.90	.0614	678	631	.0629	216	59.5		
1.00	1.91	.0611	682	637	.0623	220	57.8		
1.00	1.91	.0654	686	636	.0623	220	60.4		
1.00	1.91	.0727	689	633	.0626	218	61.4	.0495	.0800
1.00	1.92	.0506	692	650	.0611	225	61.0		
1.00	1.60	.0608	695	650	.0611	188	70.9		
1.00	1.60	.0729	695	639	.0621	185	69.2		.0772
1.00	1.61	.0500	695	654	.0608	190	67.4	.0484	
1.00	1.70	.0605	673	628	.0632	193	72.8	.0515	.0800
1.00	1.44	.0579	670	624	.0636	162	73.0		
1.00	1.61	.0607	655	611	.0650	178	70.4		
1.00	1.64	.0678	660	606	.0655	180	67.8		.0780
1.00	1.64	.0754	656	598	.0663	177	69.9		.0787
1.00	1.64	.0517	659	619	.0641	183	73.2	.0508	
1.00	1.98	.0561	660	620	.0640	222	59.0		
1.00	1.99	.0628	661	616	.0646	221	58.0		
1.00	2.00	.0694	660	609	.0652	220	57.5		
1.00	2.00	.0764	660	603	.0659	218	60.3		
1.00	2.00	.0799	661	599	.0663	216	60.3		.0806
1.00	2.00	.0507	660	621	.0639	224	57.1	.0500	
1.00	2.60	.0497	658	621	.0639	292	40.9		
1.00	2.60	.0534	655	614	.0646	288	37.4		
1.00	2.60	.0588	653	609	.0652	286	40.6		
1.00	2.61	.0639	651	602	.0659	284	40.4	.0485	
1.00	1.52	.0731	702	645	.0616	177	72.6		
1.00	1.53	.0635	713	656	.0605	181	73.9		
1.00	1.50	.0556	718	669	.0594	181	75.1	.0519	
1.00	1.73	.0562	748	699	.0568	218	73.8		
1.00	1.72	.0646	748	691	.0575	214	70.4		
1.00	1.73	.0723	750	686	.0579	214	70.7		
1.00	1.76	.0750	764	696	.0570	221	68.6		
1.00	1.77	.0549	762	715	.0555	229	70.6		
1.00	1.77	.0628	762	707	.0561	226	71.4		
1.00	1.77	.0706	762	701	.0566	224	71.6		
1.00	1.77	.0745	763	699	.0568	223	71.7		
1.00	1.75	.0794	766	697	.0571	220	71.7		.0810
1.00	1.73	.0763	769	701	.0566	219	72.5		
1.00	1.74	.0718	770	703	.0566	220	72.1		
1.00	1.75	.0675	769	707	.0566	222	72.3		
1.00	1.76	.0631	770	710	.0559	226	73.8		
1.00	1.76	.0592	769	713	.0556	227	75.5		
1.00	1.77	.0549	769	717	.0556	228	75.7		
1.00	1.77	.0510	769	720	.0555	229	73.9		
1.00	1.77	.0471	768	722	.0553	229	70.9	.0455	
1.00	1.77	.0691	768	705	.0563	225	70.7		
1.00	1.78	.0726	767	702	.0567	225	71.1		
1.00	1.78	.0757	767	699	.0571	223	71.5		
1.00	1.78	.0788	767	695	.0571	223	69.8		.0796
1.00	2.12	.0459	783	738	.0538	282	61.5		
1.00	2.14	.0519	783	734	.0541	283	61.7		
1.00	2.15	.0581	783	728	.0545	283	62.5		
1.00	2.18	.0637	782	722	.0549	284	59.4		
1.00	2.20	.0694	781	715	.0554	285	57.6		
1.00	2.29	.0761	780	710	.0559	281	57.7		
1.00	2.20	.0789	778	707	.0562	281	57.4		
1.00	2.20	.0814	778	703	.0565	279	59.3		
1.00	2.20	.0770	777	705	.0563	280	58.2		.0821
1.00	2.20	.0739	777	707	.0561	281	60.2		
1.00	2.20	.0707	776	709	.0560	281	59.0		

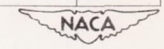

TABLE I - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH GASOLINE - Concluded

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b (^oR)	Inlet temperature T (^oR)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a
1.00	2.20	0.0676	776	712	0.0557	283	59.7		
1.00	2.20	.0638	776	717	.0554	285	60.9		
1.00	2.20	.0587	776	720	.0552	285	62.3		
1.00	2.20	.0537	776	723	.0549	287	61.3		
1.00	2.20	.0473	775	728	.0545	289	59.4		
1.00	2.20	.0448	775	731	.0544	290	58.0	0.0436	
1.50	2.52	.0496	660	623	.0955	189	72.2		
1.50	2.52	.0612	665	612	.0971	186	76.2		
1.50	2.52	.0700	666	605	.0982	184	73.0	.0474	0.0717
1.50	2.56	.0543	669	622	.0958	192	76.1		
1.50	2.57	.0497	666	624	.0955	193	72.1		
1.50	2.58	.0581	665	614	.0968	191	76.2		
1.50	2.59	.0622	661	608	.0979	190	77.6		
1.50	2.58	.0668	662	605	.0983	188	74.0	.0485	.0697
1.50	2.67	.0520	665	625	.0952	201	72.6		
1.50	2.64	.0579	665	621	.0958	197	758		.0790
1.50	2.64	.0631	665	617	.0964	196	74.4	.0463	
1.50	2.64	.0684	666	612	.0973	194	74.3		
1.50	2.63	.0739	666	607	.0981	192	74.3		
1.50	2.64	.0768	666	604	.0986	192	74.3		
1.50	2.63	.0486	666	627	.0949	199	75.0		
1.50	2.23	.0498	762	716	.0832	192	82.5	.0423	.0536
1.50	2.50	.0500	760	715	.0842	213	78.8		
1.50	2.53	.0549	760	708	.0852	213	82.6	.0417	.0658
1.50	2.48	.0616	756	703	.0857	207	77.2		
1.50	2.91	.0573	674	629	.0967	216	70.3		
1.50	2.90	.0621	677	631	.0965	215	71.6		
1.50	2.90	.0670	680	628	.0961	216	70.1		
1.50	2.89	.0721	681	625	.0978	212	73.8		
1.50	2.89	.0769	683	622	.0977	212	72.9		
1.50	2.89	.0817	684	617	.0986	210	71.2		.0845
1.50	2.92	.0809	683	617	.0982	213	71.3		
1.50	2.94	.0756	680	618	.0979	215	71.3		
1.50	2.95	.0706	677	619	.0981	215	71.6		
1.50	2.98	.0652	674	621	.0973	219	69.1		
1.50	2.97	.0608	670	622	.0975	218	70.7		
1.50	2.99	.0557	669	624	.0964	222	69.3		
1.50	2.99	.0511	668	627	.0960	223	66.9	.0475	
1.50	2.97	.0561	668	623	.0970	219	71.0		
1.50	2.93	.0664	674	621	.0970	216	68.9		
1.50	2.92	.0761	676	615	.0983	213	71.0		
1.50	3.87	.0492	670	633	.0941	295	46.4		
1.50	3.87	.0517	670	632	.0951	292	48.2		
1.50	3.87	.0538	670	630	.0955	290	49.7		
1.50	3.87	.0467	672	635	.0948	292	48.2	.0525	
1.50	3.87	.0449	672	637	.0945	293	48.0		
1.50	3.87	.0456	673	636	.0946	293	49.2		
1.50	3.87	.0477	673	635	.0945	293	48.9		
1.50	3.87	.0495	674	635	.0948	292	49.9		
1.50	3.87	.0513	674	634	.0949	292	50.4		
1.50	3.84	.0517	665	627	.0960	287	47.9		
1.50	3.87	.0488	666	629	.0957	290	47.2		
1.50	3.87	.0456	667	633	.0951	292	47.8		
1.50	3.87	.0477	669	632	.0954	291	48.5		
1.50	3.87	.0495	670	631	.0954	291	48.9		
1.50	3.87	.0513	670	631	.0954	291	50.0		
2.00	3.48	.0479	687	646	.1225	204	77.4		
2.00	3.48	.0519	689	644	.1233	202	82.3		
2.00	3.48	.0539	689	644	.1233	202	82.6		
2.00	3.48	.0559	691	648	.1215	205	75.0		
2.00	3.31	.0504	682	640	.1236	192	78.7		
2.00	3.29	.0528	685	641	.1238	190	80.5		
2.00	3.29	.0549	685	641	.1238	190	81.2		
2.00	3.29	.0570	689	642	.1234	191	83.1		
2.00	3.29	.0587	689	642	.1227	192	81.1		
2.00	3.29	.0485	690	650	.1222	193	78.0		
2.00	3.29	.0464	692	652	.1218	194	74.5	.0447	
2.00	4.13	.0471	675	638	.1244	238	61.7		
2.00	4.13	.0541	674	633	.1254	236	67.1		
2.00	4.13	.0558	673	631	.1258	235	68.6		
2.00	4.15	.0572	670	628	.1264	235	67.4		
2.00	4.15	.0589	671	627	.1265	235	69.6		
2.00	4.15	.0602	671	625	.1269	234	70.0		
2.00	4.14	.0621	671	624	.1272	233	70.0		
2.00	4.14	.0641	672	620	.1281	232	69.8		
2.00	4.14	.0654	672	620	.1280	232	70.6		
2.00	4.14	.0671	672	620	.1281	232	69.7		

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TABLE II - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH ISOPENTANE

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b (°R)	Inlet temperature T (°R)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)
1.00	2.32	0.0571	538	508	0.0781	213	48.2
1.00	2.31	.0620	538	506	.0784	211	44.7
1.00	2.31	.0672	538	505	.0786	211	45.9
1.00	2.70	.0618	538	506	.0785	247	36.4
1.00	2.15	.0544	592	559	.0710	217	52.4
1.00	2.14	.0580	595	558	.0711	216	53.3
1.00	2.13	.0629	598	559	.0710	215	53.2
1.00	2.13	.0650	600	560	.0708	215	52.1
1.00	2.12	.0710	603	557	.0712	213	53.6
1.00	2.20	.0551	598	564	.0703	224	51.5
1.00	2.17	.0598	599	561	.0707	220	52.4
1.00	2.14	.0672	602	560	.0708	216	50.5
1.00	2.12	.0733	605	559	.0710	214	55.2
1.00	2.55	.0528	607	572	.0694	263	42.5
1.00	2.55	.0565	607	571	.0695	263	40.8
1.00	2.56	.0592	608	570	.0697	263	40.5
1.00	2.56	.0629	608	567	.0700	262	41.2
1.00	2.55	.0598	608	570	.0697	262	41.8
1.00	2.55	.0542	608	574	.0692	264	41.0
1.00	1.69	.0547	683	642	.0618	196	67.8
1.00	1.69	.0586	684	640	.0620	195	69.5
1.00	1.68	.0630	685	637	.0623	193	66.9
1.00	1.68	.0673	686	635	.0625	193	66.3
1.00	1.68	.0714	688	632	.0628	192	68.2
1.00	1.68	.0755	689	631	.0629	191	68.7
1.00	1.68	.0558	690	648	.0613	196	69.3
1.00	1.68	.0510	692	651	.0609	198	68.6
1.00	1.68	.0541	693	650	.0611	197	70.9
1.00	1.68	.0606	694	646	.0615	196	69.9
1.00	1.69	.0651	694	643	.0617	196	67.6
1.00	1.68	.0722	694	639	.0621	194	68.7
1.00	1.68	.0573	696	650	.0610	197	70.3

TABLE III - SUMMARY OF COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH GASOLINE AND ISOPENTANE

Fuel	Inlet static pressure P (atm)	Inlet temperature T (°R)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Calculated parameter $\frac{P^{0.3}\,T}{V^{0.8}}$	Calculated $\eta = 7.0\,\frac{P^{0.3}\,T}{V^{0.8}}$	Difference calculated η minus observed η
Gasoline	0.50	635	275	38.5	5.75	40.2	1.7
	.50	635	235	46.5	6.53	45.7	-.8
	.50	600	245	38.0	5.95	41.6	3.6
	.50	635	225	43.0	6.78	47.5	4.5
	.75	615	245	50.0	6.88	48.2	-1.8
Gasoline	.75	630	190	64.0	8.70	60.9	-3.1
	.75	635	280	44.2	6.43	45.0	-.8
	.75	700	284	52.0	6.98	48.9	-3.1
	.75	720	290	53.4	7.06	49.4	-4.0
	.75	700	245	59.0	7.82	54.7	-4.3
Gasoline	.75	680	185	69.7	9.60	67.2	-2.5
	.75	655	250	53.0	7.24	50.7	-2.3
	1.00	620	175	71.8	10.00	70.0	-1.8
	1.00	620	220	61.0	8.31	58.2	-2.8
	1.00	620	285	43.0	6.74	47.2	4.2
Gasoline	1.00	720	285	59.3	7.82	54.7	-4.6
	1.00	700	220	71.2	9.38	65.7	-5.5
	1.00	705	183	76.0	10.92	76.4	.4
	1.00	645	190	70.0	9.71	68.0	-2.0
	1.50	615	195	74.5	10.22	71.5	-3.0
Gasoline	1.50	620	215	70.7	11.00	77.0	6.3
	1.50	635	292	48.5	7.63	53.4	4.9
	1.50	710	205	80.0	11.40	79.8	-.2
	2.00	645	202	79.0	11.27	78.9	-.1
	2.00	642	192	82.0	11.80	82.6	.6
	2.00	625	235	70.0	9.74	68.2	-1.8
Isopentane	1.00	505	211	47.5	7.01	49.1	1.6
	1.00	506	247	36.4	6.14	43.0	6.6
	1.00	560	215	53.0	7.58	53.1	.1
	1.00	570	263	41.4	6.59	46.1	4.7
	1.00	640	195	69.0	9.41	65.9	-3.1

TABLE IV - COMBUSTION EFFICIENCY DATA FOR CONE FLAME HOLDER IN 2-INCH RAM-JET-TYPE COMBUSTOR WITH PENTANE (FROM REFERENCE 4)

Inlet static pressure P (atm)	Inlet temperature T (°R)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Calculated parameter $\frac{P^{0.3}\,T}{V^{0.8}}$
0.133	610	339	20	3.14
.20	610	339	21.4	3.55
.267	610	327	26	4.02
.373	610	291	32	5.15
.516	610	278	40	5.56
.667	610	266	43.4	5.88
2.9	610	254	79	9.98

TABLE V - COMBUSTION EFFICIENCY DATA FOR CONE FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH GASOLINE AND ISOPENTANE

Fuel	Inlet static pressure P (atm)	Inlet temperature T (°R)	Inlet velocity V (ft/sec)	Fuel-air ratio f/a	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a
Gasoline	0.97	665	203	0.0599	75.9		
	1.00	667	199	.0556	80.4		
	1.00	670	199	.0527	82.7		
	1.00	673	201	.0495	83.7	0.0482	
	1.00	667	199	.0600	78.6		
Gasoline	1.00	665	198	.0630	77.7		
	1.00	663	198	.0655	75.6		
	1.00	660	197	.0689	74.5		0.0756
	.75	675	253	.0548	69.8		
	.75	671	251	.0569	69.9		
Gasoline	.75	669	251	.0596	68.4		
	.76	667	246	.0628	67.0		
	.78	665	237	.0672	65.4	.0532	.0685
	.75	671	202	.0611	77.5		
	.75	671	202	.0561	79.4	.0554	
Gasoline	.75	668	201	.0587	78.6		
	.75	664	200	.0640	75.7		
	.75	660	199	.0680	73.4		.0729
	1.00	670	245	.0586	68.4		
	1.00	666	241	.0612	68.5		
Gasoline	1.00	662	236	.0633	69.8		
	1.00	658	234	.0662	67.6		.0772
	1.00	664	248	.0565	68.4		
	1.00	665	251	.0525	69.5	.0492	
	1.25	663	174	.0610	86.0		
Gasoline	1.25	660	173	.0642	83.4		
	1.25	657	171	.0668	81.0		
	1.25	656	171	.0693	81.1		
	1.25	654	170	.0730	80.1		.0815
	1.25	656	174	.0578	88.9		
Gasoline	1.25	670	175	.0531	90.1	.0475	
	1.00	765	203	.0684	78.5		
	1.00	765	205	.0591	86.0		
	1.00	767	205	.0573	87.4		
	1.00	769	206	.0556	88.0		
Gasoline	1.00	772	206	.0537	88.3		
	1.00	773	207	.0516	89.9		
	1.00	776	209	.0479	88.6	.0442	
	1.00	765	208	.0619	82.7		
	1.00	759	206	.0657	80.1		
Gasoline	1.00	754	205	.0693	78.9		
	1.00	751	204	.0728	79.2		
	1.00	749	204	.0763	78.8		.0800
	.75	768	253	.0559	78.1		
	.75	770	251	.0527	79.9	.0488	
Gasoline	.75	767	252	.0601	75.9		
	.75	761	246	.0651	72.4		
	.75	759	250	.0679	71.1		
	.75	755	247	.0723	71.6		.0740
	.75	750	178	.0717	83.7		
Gasoline	.75	750	178	.0660	83.9		
	.75	752	180	.0603	89.8		
	.75	754	181	.0547	91.6	.0521	
	.75	735	178	.0760	81.2		.0792
	.50	738	260	.0654	63.3		
Gasoline	.50	738	257	.0598	69.1		
	.50	741	256	.0545	71.0		
	.50	727	253	.0707	64.7		.0715
	.50	715	171	.0673	80.5		
	.50	700	171	.0733	80.1		
Gasoline	.50	708	171	.0626	78.5		
	.50	670	251	.0607	61.5		
	.50	668	254	.0563	60.2		
	.50	670	257	.0517	58.4		
	.50	658	252	.0631	59.2		
	.50	654	250	.0667	55.9		
Isopentane	1.00	574	193	.0691	63.8		
	1.00	572	191	.0722	67.4		
	1.00	569	191	.0750	68.4		.0790
	1.00	574	193	.0660	63.3		
	1.00	576	194	.0630	63.7	.0630	
	1.00	577	192	.0667	63.9		
	1.00	576	192	.0663	64.2		

TABLE VI - SUMMARY OF COMBUSTION EFFICIENCY DATA FOR CONE FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR AT STOICHIOMETRIC FUEL-AIR RATIO WITH GASOLINE AND ISOPENTANE

Fuel	Inlet static pressure P (atm)	Inlet temperature T (^{o}R)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	$\frac{P^{0.3}\,T}{V^{0.8}}$
Gasoline	0.50	662	255	60.0	6.40
	.50	707	171	79.5	9.42
	.50	734	256	66.5	7.10
	.75	665	200	78.3	8.78
	.75	669	245	68.0	7.52
	.75	742	180	88.5	10.63
	.75	762	250	76.0	8.42
	1.00	664	242	69.0	8.20
	1.00	666	200	78.5	9.57
	1.00	761	206	85.0	10.71
	1.25	662	173	87.0	11.56
Isopentane	1.00	574	192	64.0	8.50

TABLE VII - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH BENZENE

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b (^{o}R)	Inlet temperature T (^{o}R)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a	Equivalence ratio
0.69	1.05	0.0619	721	670	0.0411	183	66.6			0.821
.69	1.05	.0677	723	663	.0413	182	70.6			.898
.69	1.05	.0746	723	660	.0415	181	68.7			.990
.69	1.05	.0810	723	653	.0420	179	74.6			1.073
.69	1.05	.0876	723	649	.0422	178	77.4			1.160
.69	1.05	.0937	723	644	.0425	177	78.3			1.243
.69	1.06	.0996	723	639	.0431	176	77.3			1.320
.69	1.06	.1061	---	---	-----	---	----		0.1061	1.410
.69	1.06	.0612	723	668	.0412	185	67.4			.812
.69	1.06	.0562	---	---	-----	---	----	0.0562		.745
.69	1.60	.0576	729	680	.0403	284	47.7			.763
.69	1.60	.0616	729	675	.0406	282	48.0			.816
.69	1.60	.0661	730	670	.0407	281	49.6			.876
.69	1.58	.0712	730	667	.0410	276	51.6			.934
.69	1.58	.0750	731	663	.0413	277	52.6			.994
.69	1.58	.0794	731	660	.0413	277	56.5			1.052
.69	1.59	.0846	731	656	.0418	272	60.3			1.122
.69	1.59	.0889	731	654	.0419	272	62.0			1.179
.69	1.59	.0554	---	---	-----	---	----	.0554		.735
.69	1.59	.0936	---	---	-----	---	----		.0936	1.241

TABLE VIII - COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH PROPYLENE OXIDE

Inlet static pressure P (atm)	Air flow m_a (lb/sec)	Fuel-air ratio f/a	Air temperature before fuel T_b ($^\circ$R)	Inlet temperature T ($^\circ$R)	Inlet density ρ (lb/cu ft)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	Lean blow-out f/a	Rich blow-out f/a	Equivalence ratio
0.68	1.05	0.0903	689	605	0.0448	168	80.9			0.857
.68	1.05	.1203	690	579	.0469	160	75.4			1.148
.68	1.07	.1471	690	556	.0486	158	88.5			1.400
.68	1.07	.1681	---	---	-----	---	----		0.1681	1.600
.68	1.06	.1048	696	603	.0450	168	81.5			1.000
.68	1.05	.1348	697	573	.0473	159	85.8			1.280
.68	1.05	.1621	697	550	.0491	153	90.4			1.450
.68	1.58	.0682	712	643	.0422	267	52.1			.650
.68	1.58	.0762	715	636	.0427	264	62.2			.725
.68	1.58	.0839	717	631	.0430	263	67.6			.799
.69	1.60	.0905	718	626	.0436	263	71.4			.861
.73	1.63	.0968	720	620	.0470	248	76.3			.922
.77	1.60	.1063	720	616	.0497	230	73.9			1.012
.78	1.59	.1147	720	607	.0510	223	70.9			1.090
.78	1.59	.1204	721	602	.0517	220	68.9			1.148
.79	1.61	.1389	722	583	.0536	215	74.7			1.320
.79	1.61	.0639	---	---	-----	---	----	0.0639		.690
.33	.79	.0914	699	615	.0215	263	54.0			.870
.33	.81	.0832	698	614	.0215	268	54.0			.793
.33	.80	.0774	697	618	.0214	267	49.8			.737
.33	.80	.0715	---	---	-----	---	----	.0715		.680
.33	.80	.0965	697	605	.0219	262	54.0			.919
.33	.79	.1044	695	596	.0222	255	51.3			1.000
.33	.79	.1108	694	591	.0224	252	57.9			1.052
.33	.79	.1174	693	583	.0227	249	57.6			1.120
.33	.79	.1241	693	579	.0229	247	58.6			1.182
.33	.79	.1308	692	574	.0230	245	61.1			1.245
.33	.79	.1523	---	---	-----	---	----	.1523		1.450

TABLE IX - SUMMARY OF COMBUSTION EFFICIENCY DATA FOR V-GUTTER FLAME HOLDER IN 5-INCH RAM-JET-TYPE COMBUSTOR WITH BENZENE AND PROPYLENE OXIDE AT EQUIVALENCE RATIO OF 1.0

Fuel	Inlet static pressure P (atm)	Inlet temperature T ($^\circ$R)	Inlet velocity V (ft/sec)	Combustion efficiency η_b (percent)	$\frac{P^{0.3}\,T}{V^{0.8}}$	$\frac{P^{0.3}\,T}{V^{0.8}}\left(\frac{u_f}{u_{f,g}}\right)^{1.1}$
Benzene	0.69	665	182	73	9.27	10.20
	.69	665	280	54	6.54	7.35
Propylene oxide	.68	603	168	81.5	8.90	14.80
	.73	620	250	75	6.80	11.30
	.33	600	260	55	5.03	8.35

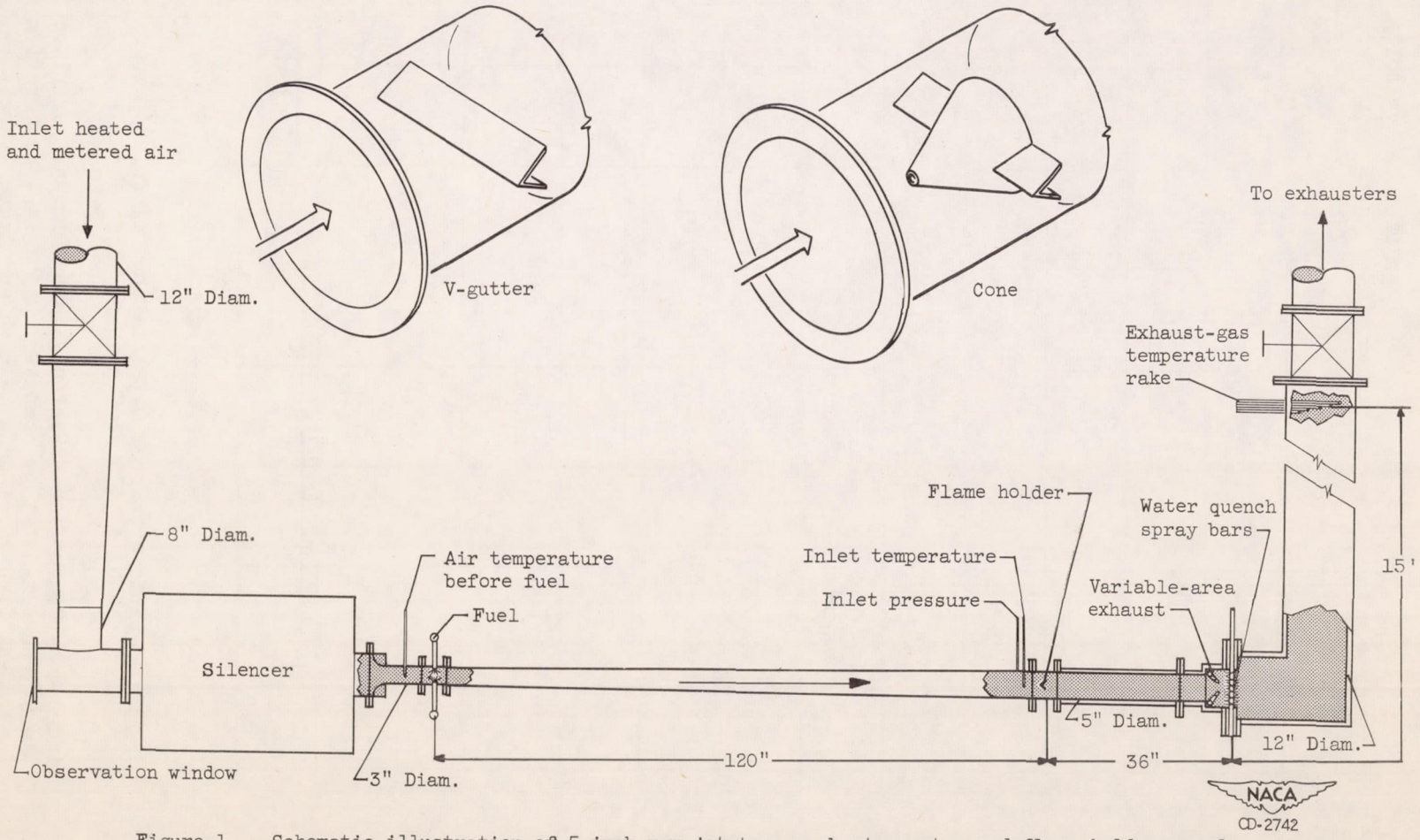
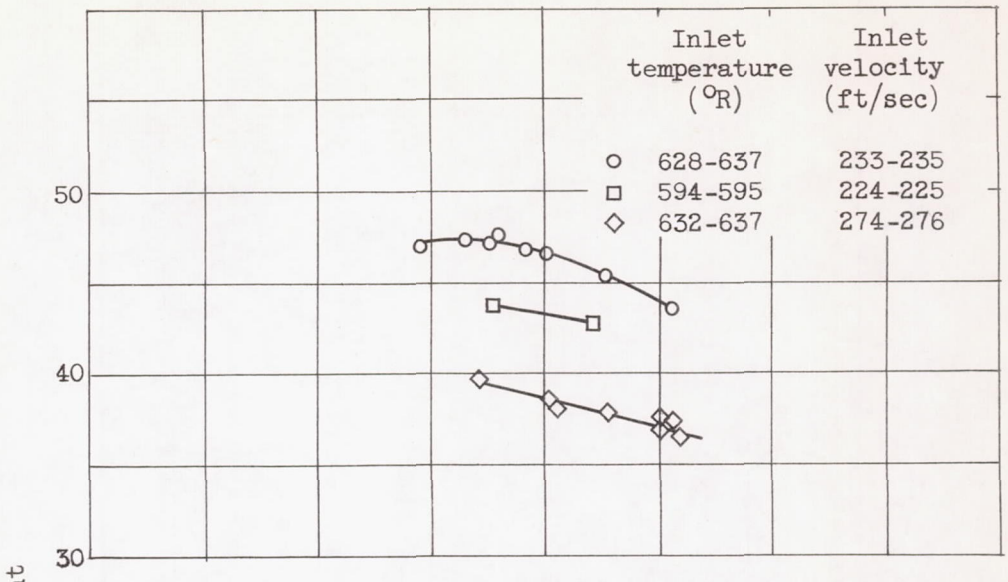
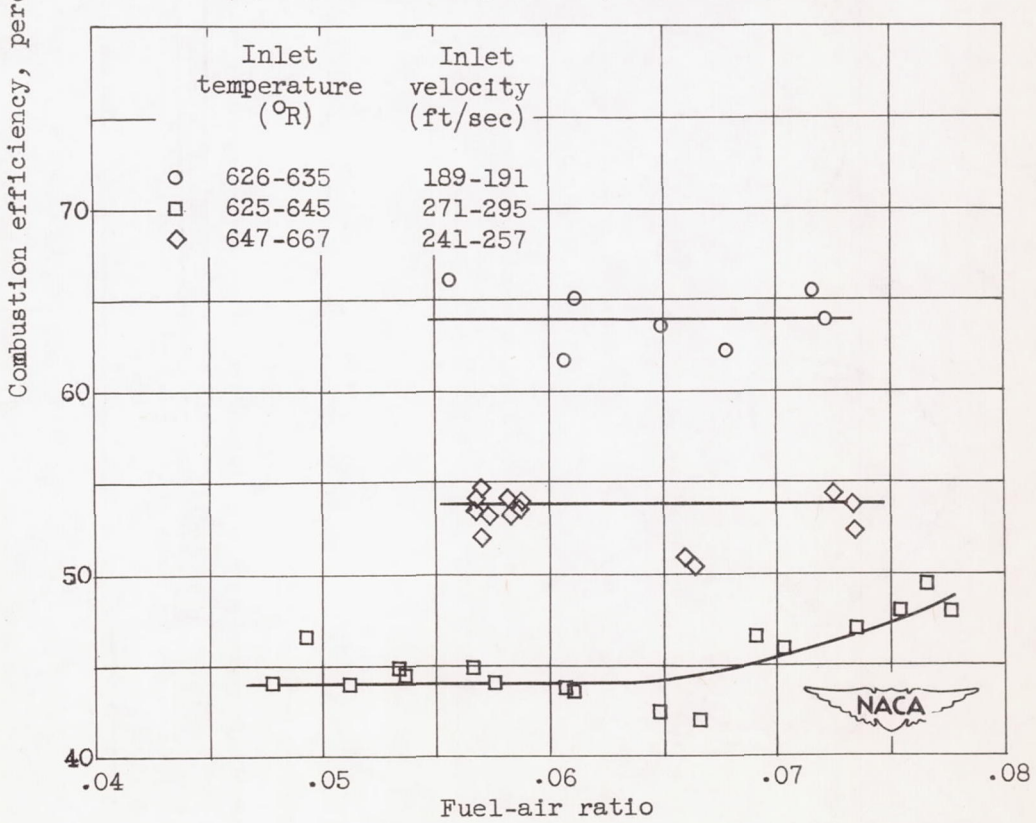


Figure 1. - Schematic illustration of 5-inch ram-jet-type combustor setup and flame holders used.

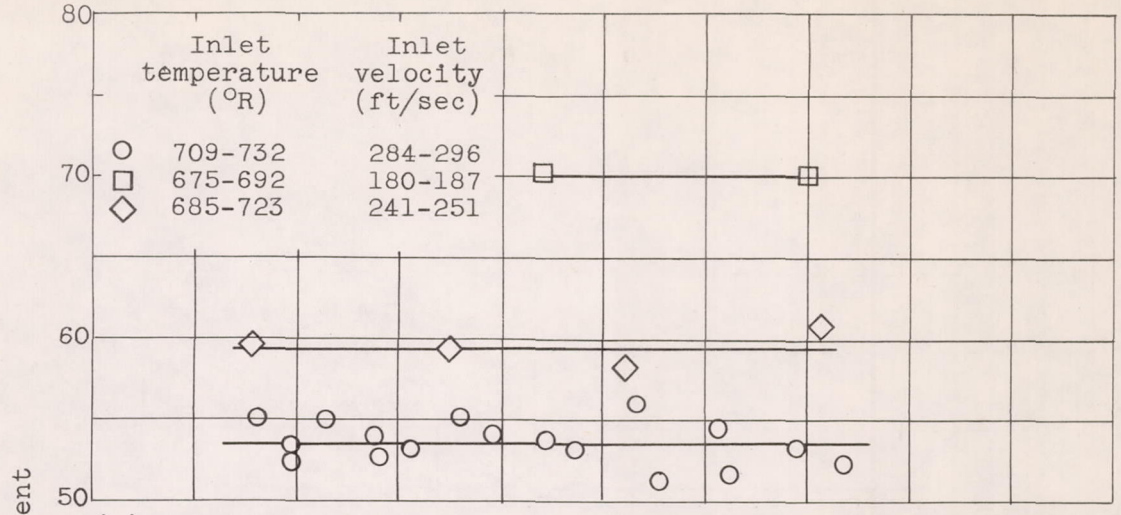


(a) Inlet static pressure, 0.5 atmosphere.

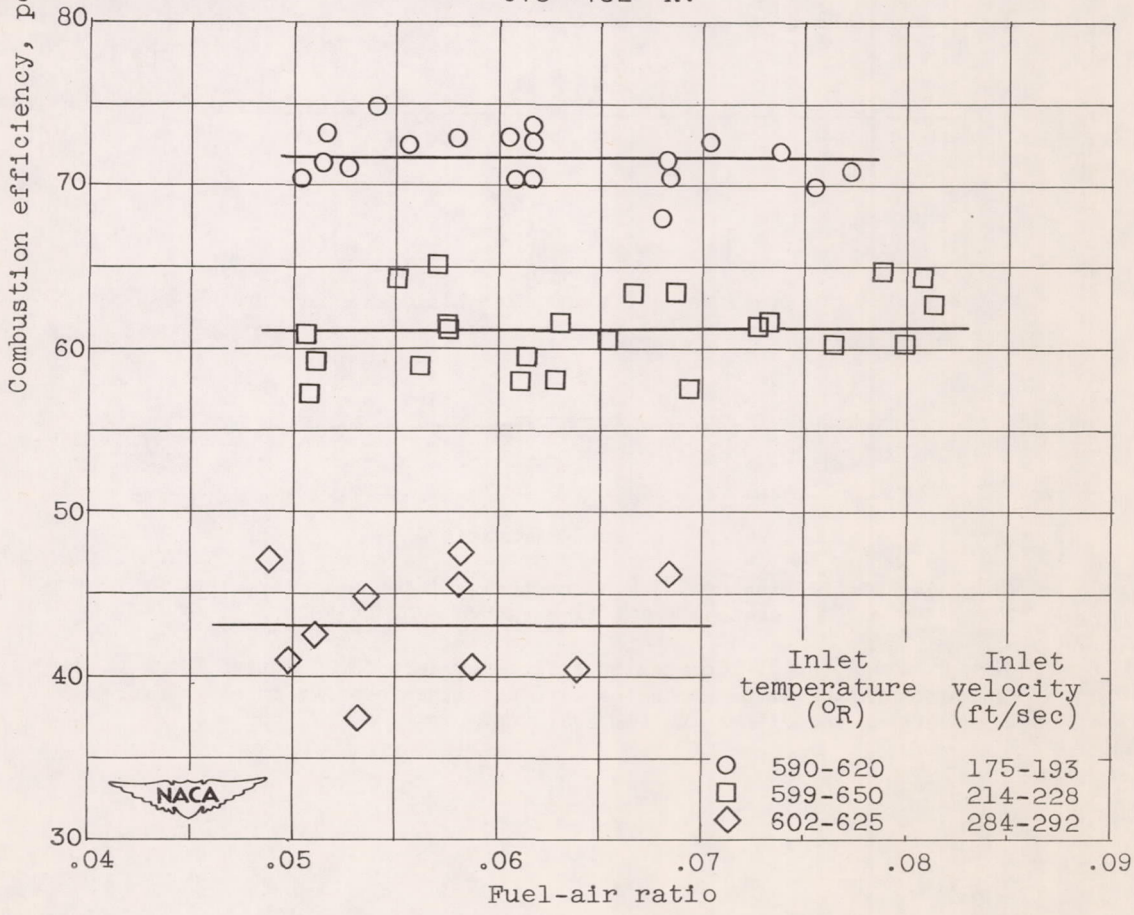


(b) Inlet static pressure, 0.75 atmosphere; inlet temperature, 625°-667° R.

Figure 2. - Combustion efficiency data for V-gutter flame holder in 5-inch ram-jet-type combustor with gasoline for five inlet pressures with varying velocities and temperatures.

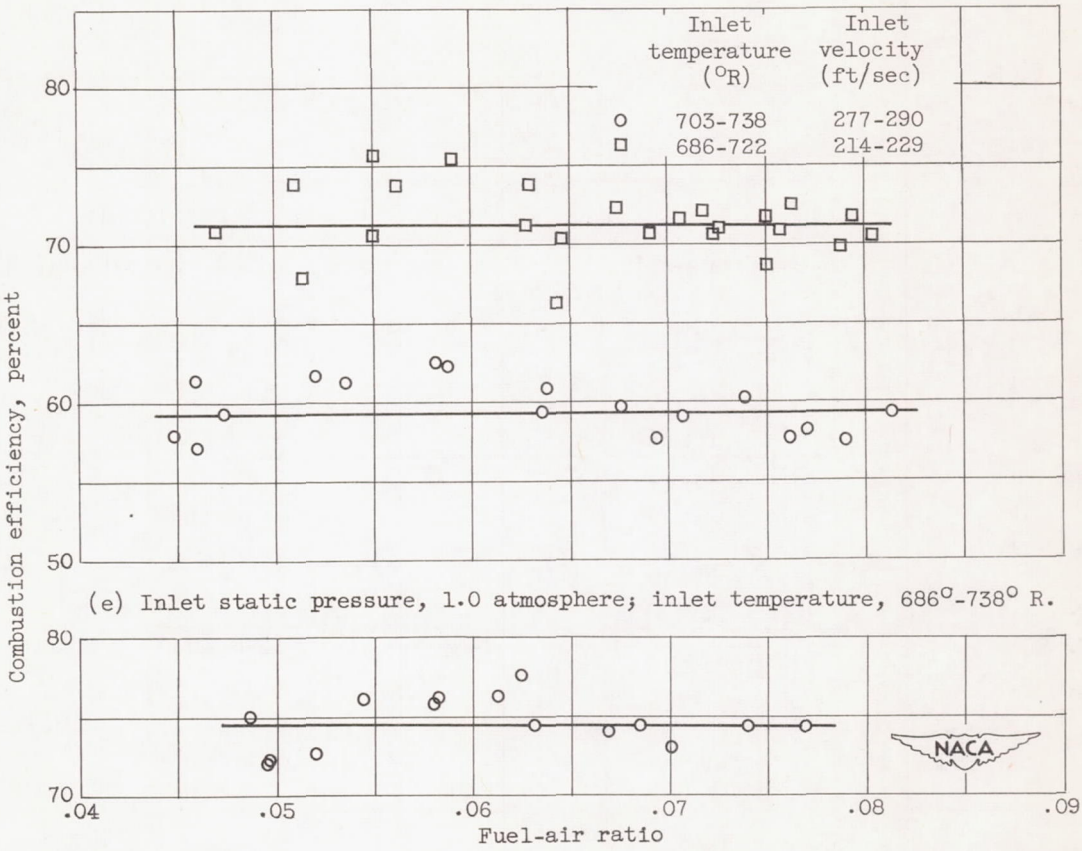


(c) Inlet static pressure, 0.75 atmosphere; inlet temperature, 675°-732° R.



(d) Inlet static pressure, 1.0 atmosphere; inlet temperature, 590°-650° R.

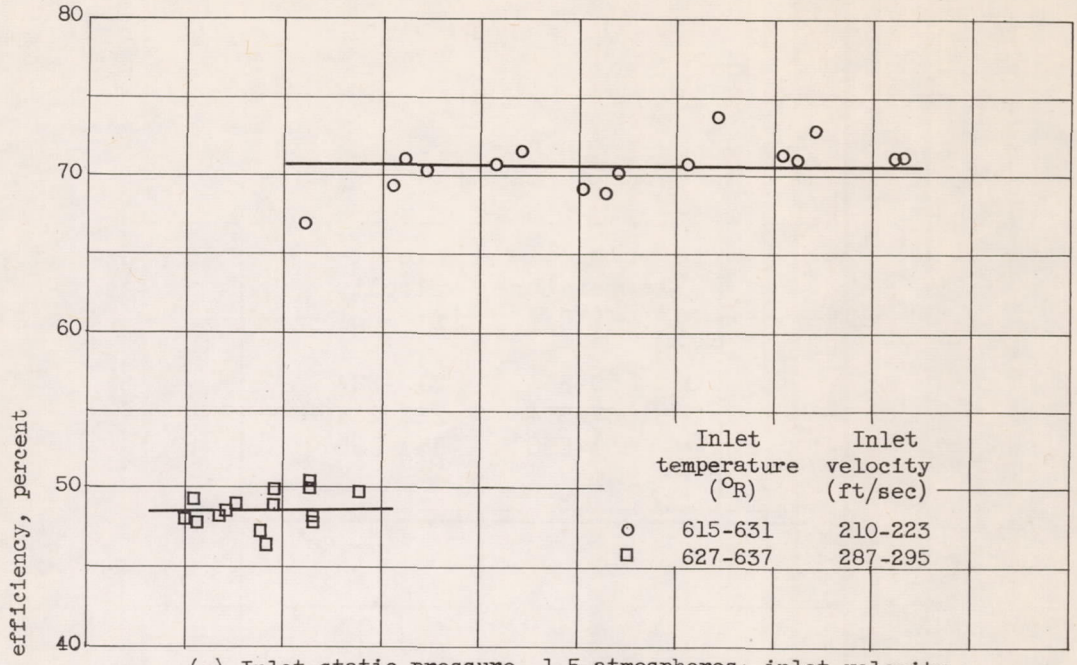
Figure 2. - Continued. Combustion efficiency data for V-gutter flame holder in 5-inch ram-jet-type combustor with gasoline for five inlet pressures with varying velocities and temperatures.



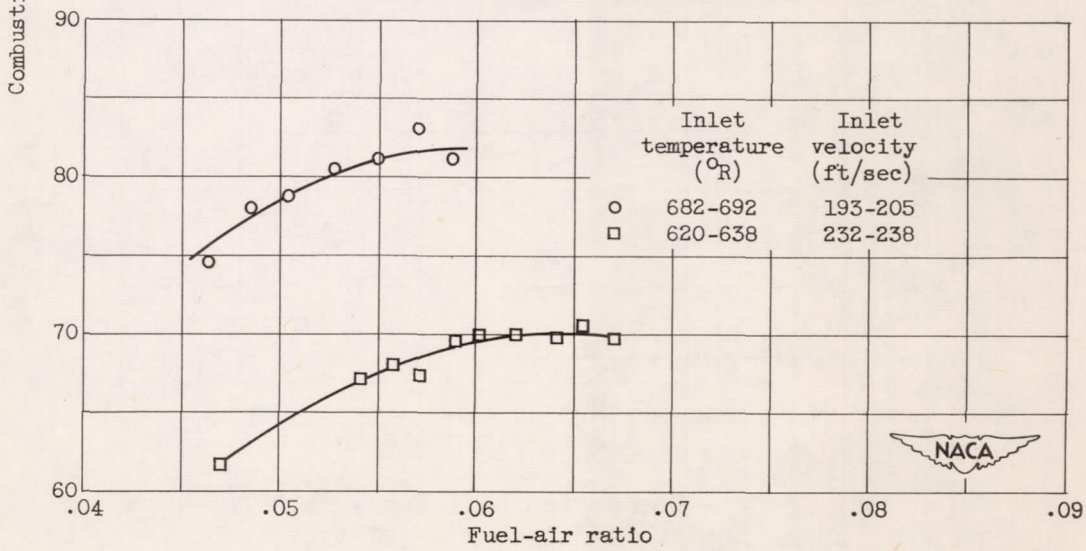
(e) Inlet static pressure, 1.0 atmosphere; inlet temperature, 686°-738° R.

(f) Inlet static pressure, 1.5 atmospheres; inlet velocity, 188-201 feet per second; inlet temperature, 605°-627° R.

Figure 2. - Continued. Combustion efficiency data for V-gutter flame holder in 5-inch ram-jet-type combustor with gasoline for five inlet pressures with varying velocities and temperatures.



(g) Inlet static pressure, 1.5 atmospheres; inlet velocity, 210-295 feet per second.



(h) Inlet static pressure, 2.0 atmospheres.

Figure 2. - Concluded. Combustion efficiency data for V-gutter flame holder in 5-inch ram-jet-type combustor with gasoline for five inlet pressures with varying velocities and temperatures.

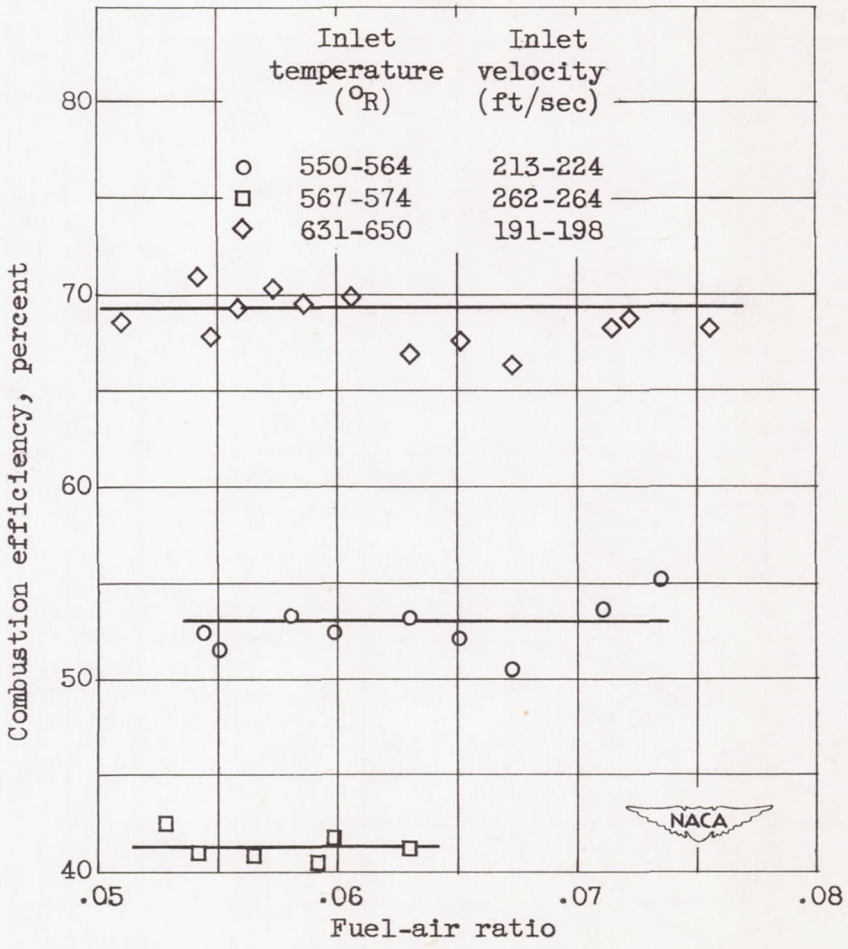


Figure 3. - Combustion efficiency data for V-gutter flame holder in 5-inch ram-jet-type combustor with isopentane at three inlet air velocities. Inlet static pressure, 1 atmosphere.

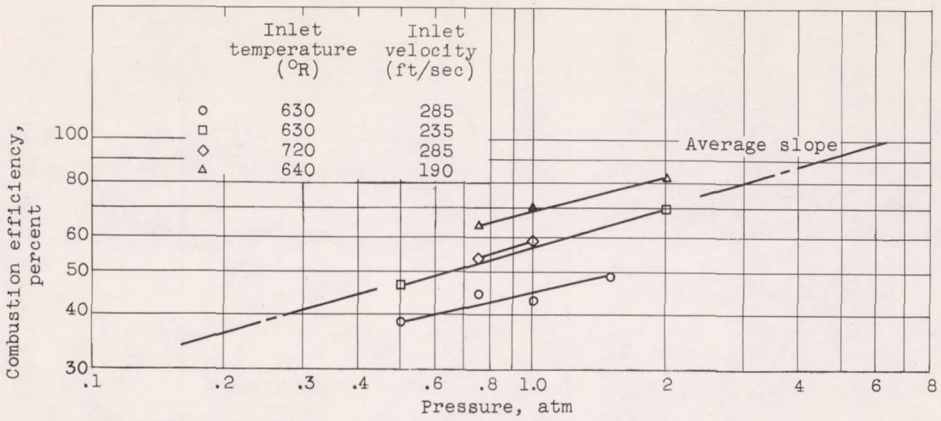


Figure 4. - Effect of inlet static pressure on combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor at equivalence ratio of 1.0.

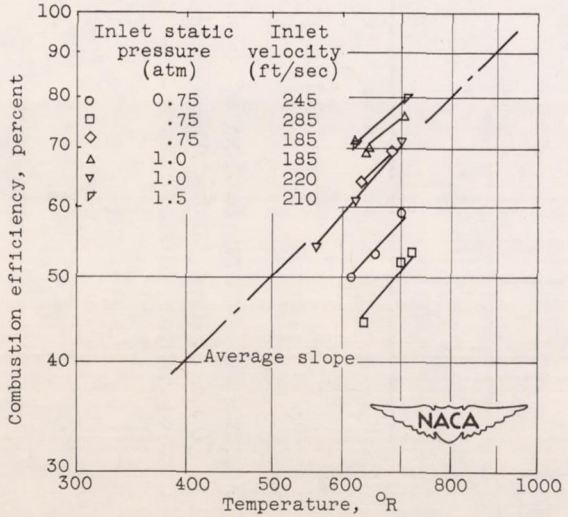


Figure 5. - Effect of temperature on combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor at equivalence ratio of 1.0.

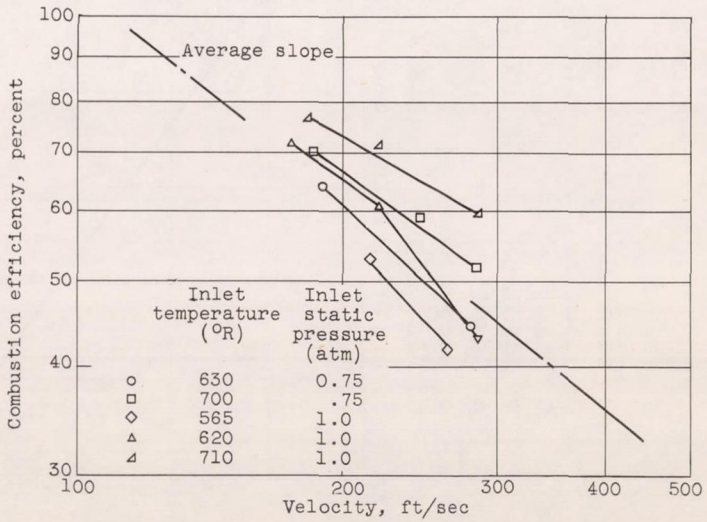


Figure 6. - Effect of velocity on combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor at equivalence ratio of 1.0.

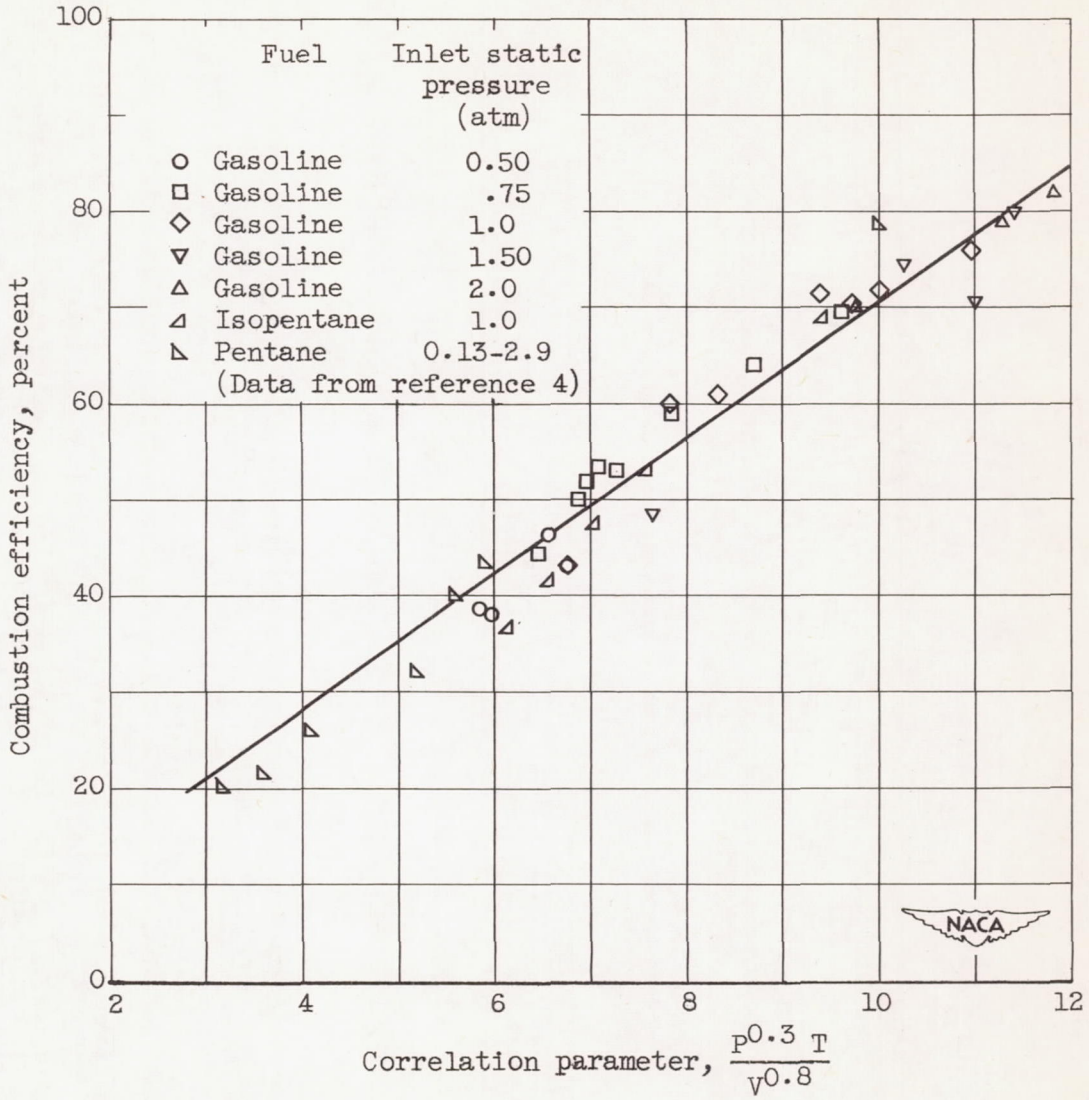
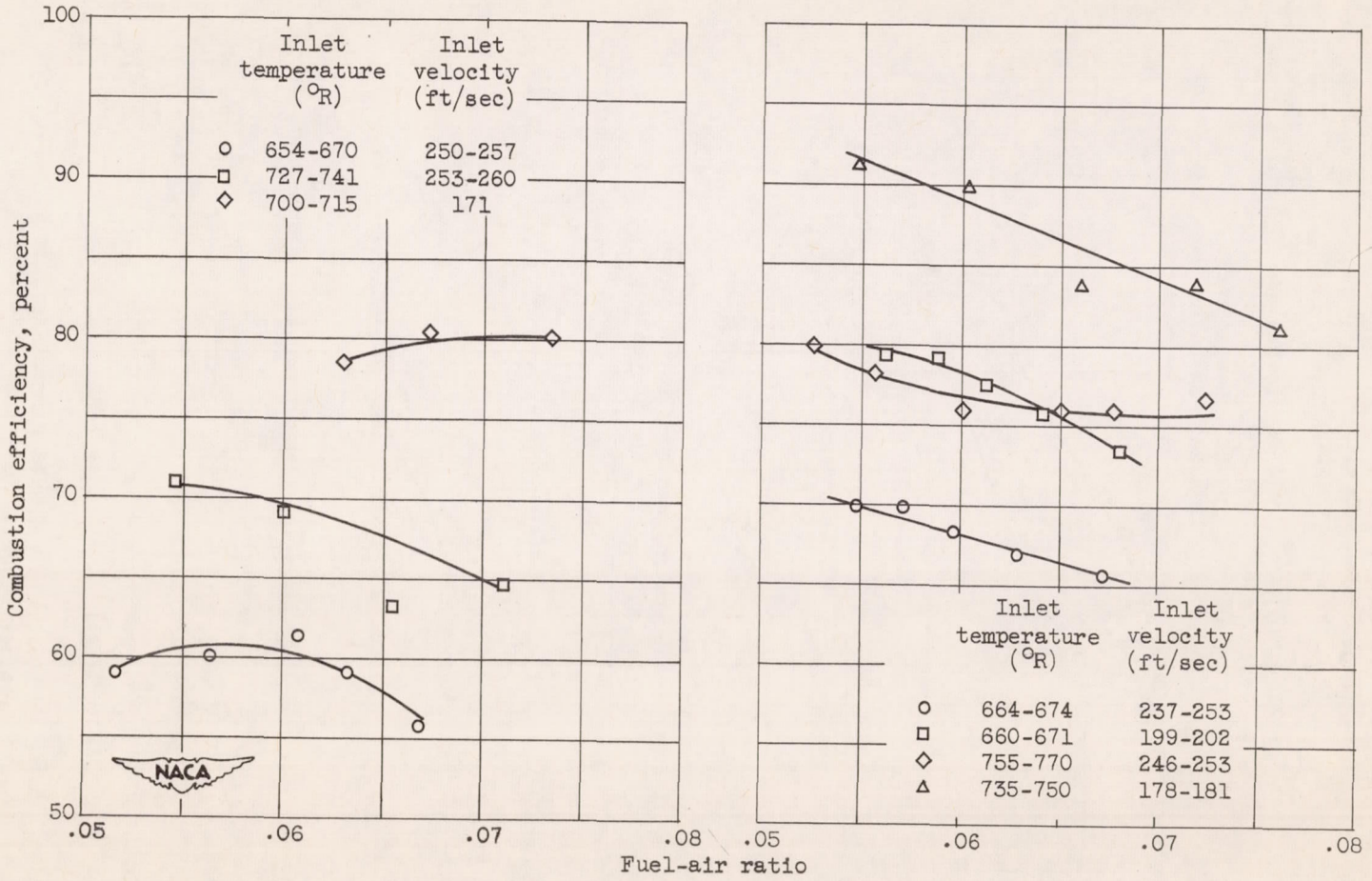


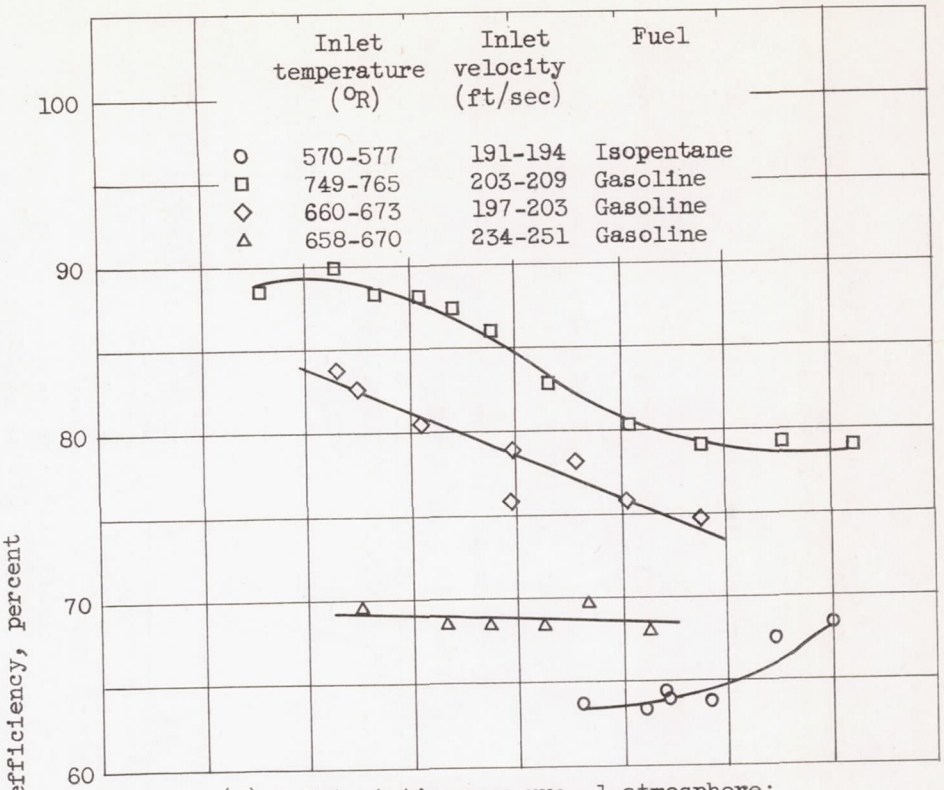
Figure 7. - Correlation of combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor with gasoline, isopentane, and pentane.



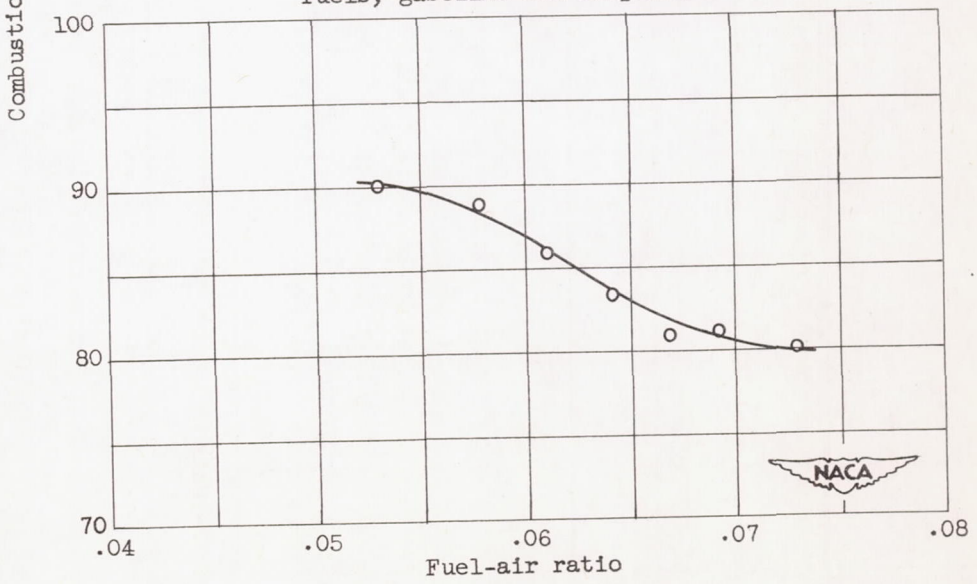
(a) Inlet static pressure, 0.5 atmosphere; fuel, gasoline.

(b) Inlet static pressure, 0.75 atmosphere; fuel, gasoline.

Figure 8. - Combustion efficiency data for cone flame holder in 5-inch ram-jet-type combustor with gasoline and isopentane for four pressures.



(c) Inlet static pressure, 1 atmosphere; fuels, gasoline and isopentane.



(d) Inlet static pressure, 1.25 atmospheres; inlet velocity, 170-175 feet per second; inlet temperature, 654°-670° R; fuel, gasoline.

Figure 8. - Concluded. Combustion efficiency data for cone flame holder in 5-inch ram-jet-type combustor with gasoline and isopentane for four pressures.

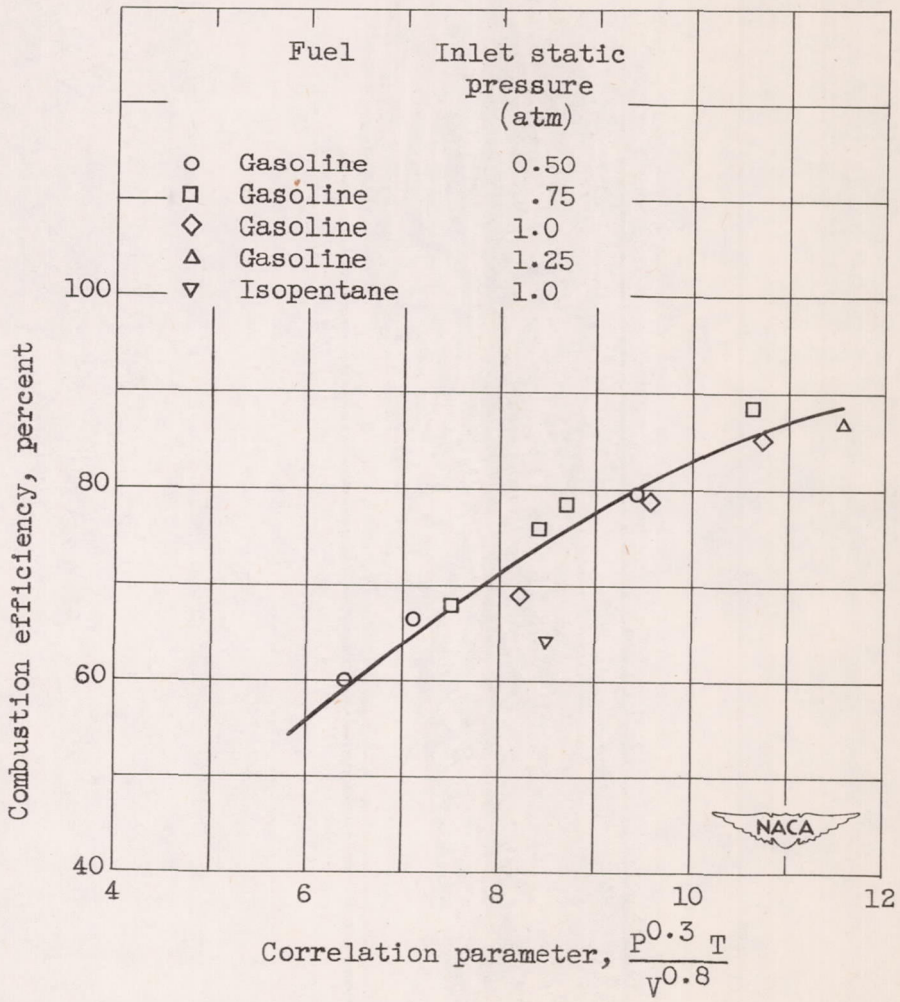
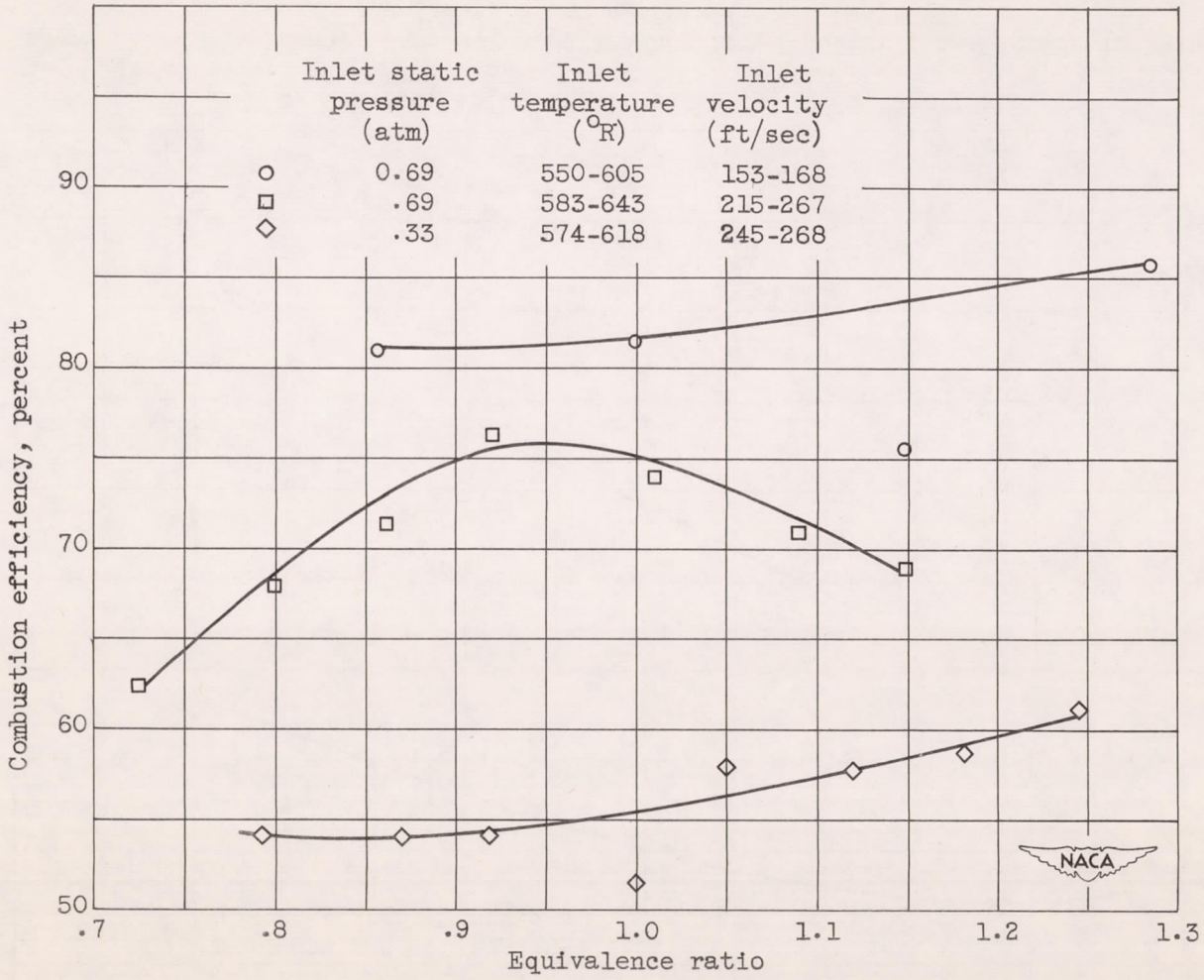


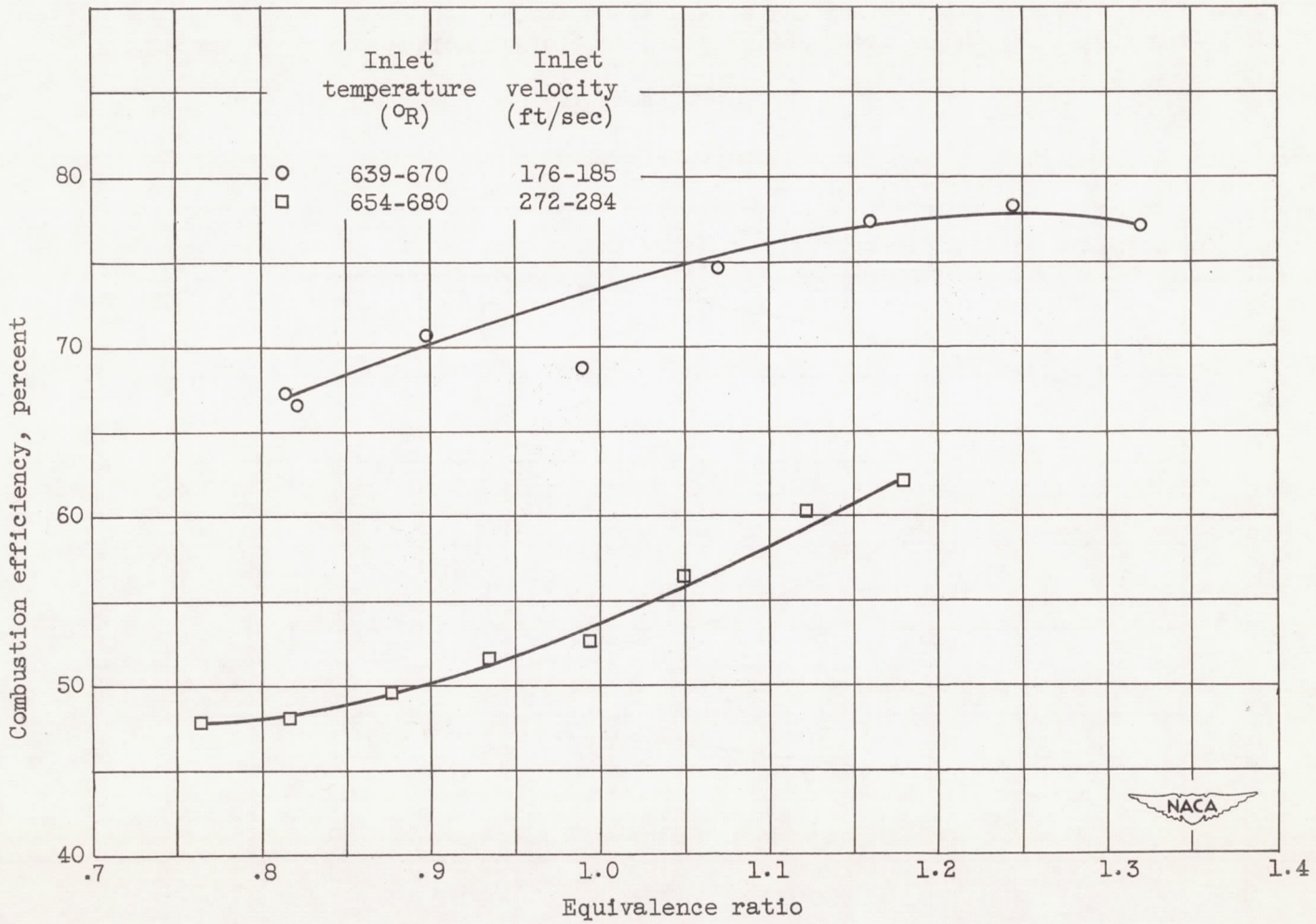
Figure 9. - Correlation of combustion efficiency for cone flame holder in 5-inch ram-jet-type combustor with gasoline and isopentane.

Figure 10. - Schematic illustration of instantaneous cross section of flame in 5-inch ram-jet-type combustor.



(a) Propylene oxide

Figure 11. - Combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor with two fuels.



(b) Benzene; inlet static pressure, 0.69 atmosphere.

Figure 11. - Concluded. Combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor with two fuels.

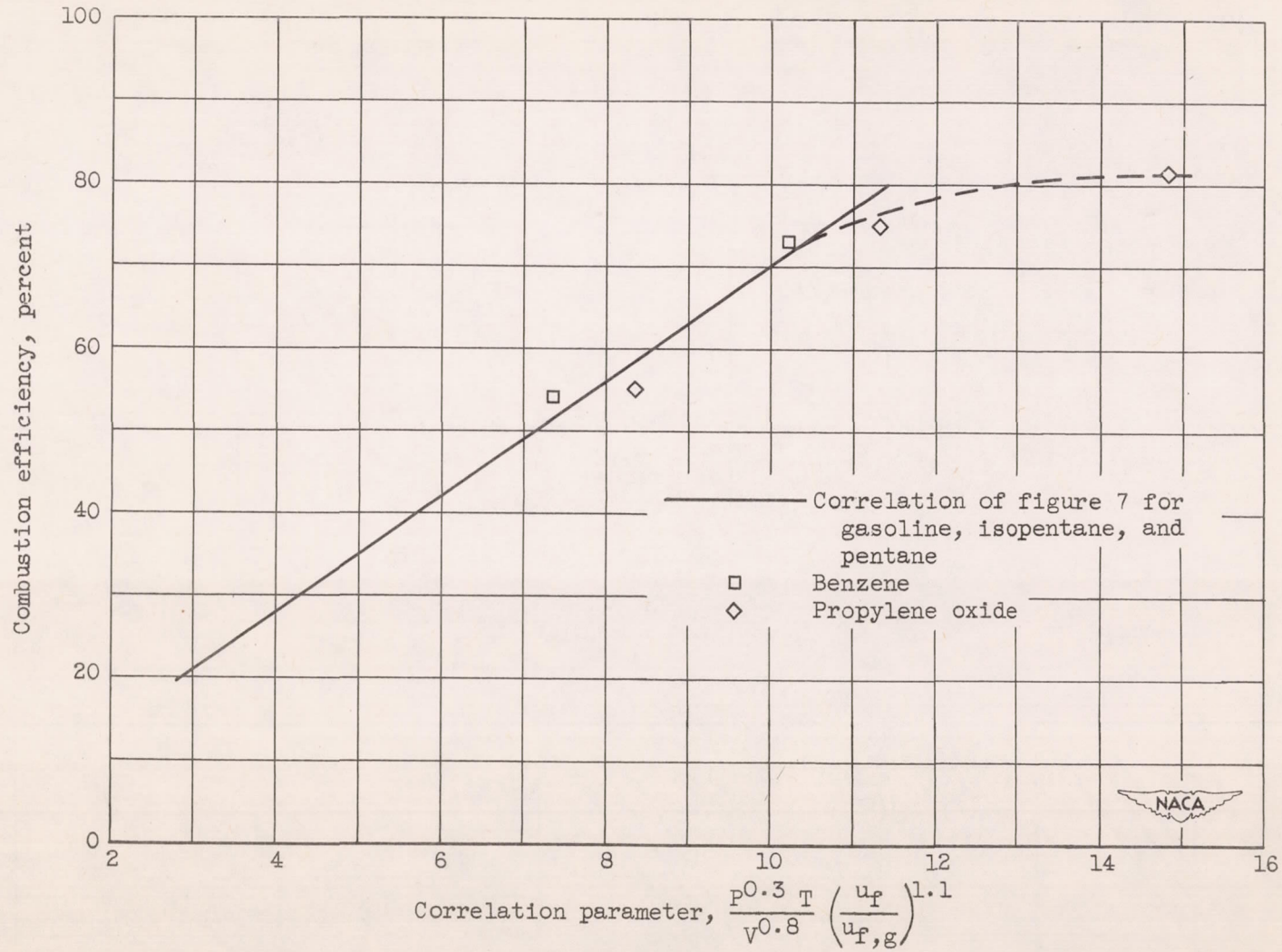
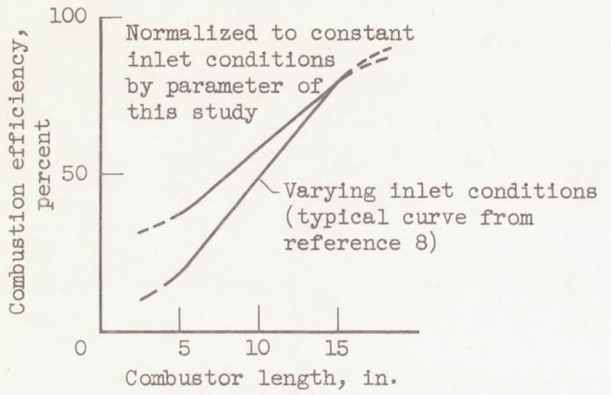
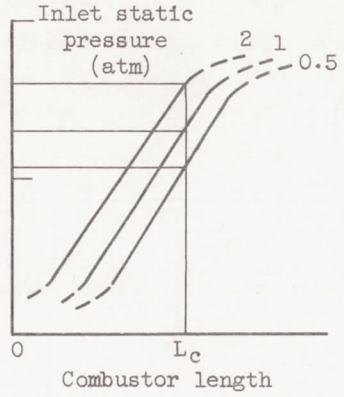


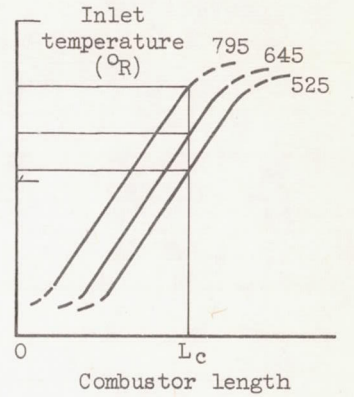
Figure 12. - Correlation of combustion efficiency for V-gutter flame holder in 5-inch ram-jet-type combustor with gasoline, isopentane, pentane, benzene, and propylene oxide.



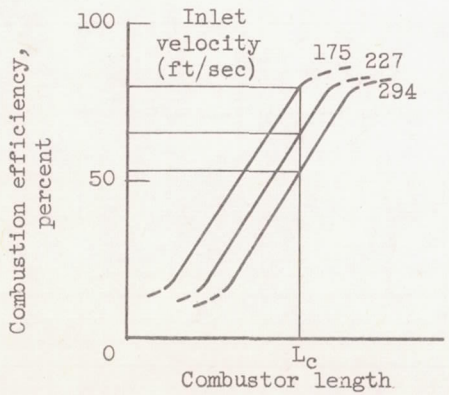
(a) Effect of varying inlet conditions.



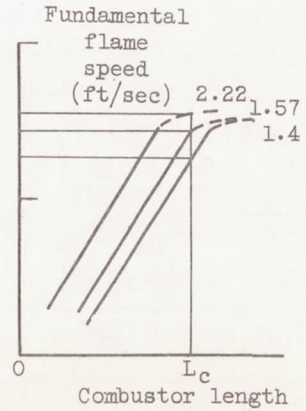
(b) Pressure variation. (T, 770° R; V, 250 ft/sec; u_f, 1.4 ft/sec.)



(c) Temperature variation. (P, 1 atm; V, 200 ft/sec; u_f, 1.4 ft/sec.)



(d) Velocity variation. (P, 1 atm; T, 710° R; u_f, 1.4 ft/sec.)



(e) Fundamental flame speed variation. (P, 2/3 atm; T, 660° R; V, 180 ft/sec.)

Figure 13. - Some typical combustion efficiency against combustor length curves.